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DEPARTMENT OF WATER RESOURCES

F. L. GRINDLEY
DIRECTOR

REPORT

ON

IRRIGATION WATER USE STUDY

A. G. Underhill
Water Resources
Government of Alberta

October 1963

Edmonton, Alberta, Canada

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IRRIGATION WATER USE

by A.G. UNDERHILL, Chairman

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Final Draft

IRRIGATION WATER USE REPORT

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United States Bureau of Reclamation

United States Department of Agriculture

Canadian Department of Agriculture

The Alberta Irrigation Districts

and the 21 State Governments in whose states irrigation is generally practised.

INTRODUCTION.

The amount of water required to irrigate a parcel of land has long been the subject of research and of some controversy. The need for a uniform approach to calculate the needs for irrigation projects in the Prairie Provinces has become more apparent as the water requirements in the area have increased for various purposes.

The present series of dry years along with the expansion of the St. Mary River project and the Bow River project in Alberta has made it abundantly clear that the present allocations and the method of calculating these allocations are not satisfactory. They do not provide sufficient water to allow for all the losses which occur in delivering the water to the plant. It has, therefore, become necessary to reassess the methods used and the assumptions which are necessary to calculate the requirements for the various projects, both existing and proposed in the three prairie provinces.

The allocations made for various Alberta projects by the Prairie Provinces Water Board in 1951 have proved to be insufficient to meet the irrigation requirements and in 1963 a request was made to the PPWB to have these allocations increased.

A question of the interpretation of what an allocation meant has also been the subject of considerable controversy.

It was with these problems in mind that on January 17th, 1963 the "Irrigation Water Use" Committee was set up by the Prairie Provinces Water Board. The Committee comprised the following members:

A. G. Underhill - District Engineer
Alberta Water Resources - Chairman

R. D. May - District Engineer
Federal Water Resources

J.G. McMorine - PFRA - Hydrology Engineer

The terms of reference were as follows:

"The Committee will report on allocation procedures used by various agencies, on methods of computing gross diversions used by various agencies, and the procedures under which diversion requirements are administered. If sufficient data are available the committee will recommend procedures for computing gross irrigation diversion requirements for the prairie area. It would be in order for the committee to suggest what further data or research would be required if such recommendation cannot be made at this time.

The committee will also review allocations made by the P.P.W.B. and suggest those that need revision. Finally the committee will prepare a standard form which might be used by the Board in receiving requests for and in authorizing allocations of water.

Meetings were held in Calgary on February 8th, 1963 and at various Alberta Irrigation District headquarters during May 14th to 17th, 1963.

In addition the Chairman visited the Saskatchewan Government and the PFRA office during May 9th & 10th to discuss the problem.

SUMMARY.

The problem of the amount of water required to irrigate an acre of land is a complex one. It has received considerable study over the years both here and elsewhere.

The approach generally to the problem has been to attempt to determine the amount of water which is required in evapotranspiration or consumptive use.

The studies into this aspect of irrigation water use take considerable time and for every change in location a different amount of water is required depending on various climatic and soil conditions.

Many investigators have developed empirical formulae to solve the problem of plant consumptive use. In this report the more common formulae will be discussed.

Once the amount of water is known for the type of vegetation you wish to grow, then it is necessary to determine the efficiency with which this water can be applied to the land. Losses due to evaporation, seepage and waste all occur in moving the water in ditches from the farm headgate to the soil storage reservoir so that it is available for plant use. These losses must be determined, but to date there has been little research into the actual losses. The problem is complex and further research is required to accurately determine these losses.

In the meantime our present knowledge, along with research elsewhere will allow an estimate to be made of these losses. This means we can determine the amount of water required at the farm delivery point by deducting the effective rainfall from the plant consumptive use and adding to it the water that will be lost and wasted in getting the water to the plant.

Similarly, although a great deal of research has been undertaken no easy way has been found to calculate the losses which occur in carrying the water from the point of diversion on a source of supply to the farm headgate. Estimates have been made by specialists in the irrigation field in Alberta over the years as to the conveyance losses for individual projects. These agree well with other similar areas and have been accepted.

By accepting certain criteria we are therefore able to compute:

(a) plant requirements

(b) gross diversion

(c) farm delivery

It then becomes necessary to decide which of these should be the figure used in the allocation of water. It appears that in the more important inter-agency treaties signed here and elsewhere that the main requirement has been "how much water can we take from the stream for the project". In most cases the "net depletion" from a stream has been the controlling factor both interstate wise and internationally in the United States. This appears to be a sound premise, and, although the gross diversion must be known in order to assure the correct amount of water being available in the stream, at the point of diversion, the users downstream are only interested in the amount they can expect in the stream channel and the quality of the water available. For this reason we have concerned ourselves in checking elsewhere to find if this is a satisfactory means of control.

Having now decided that we should allocate water on the basis of net depletion to the stream we must now find a method of calculating it. The net depletion is the difference between the total amount of water diverted from the stream and the amount of water returned to be used downstream. We can calculate the gross diversion by one of the empirical formulae for consumptive use and by using estimates for farm efficiency and conveyance losses.

We can only measure part of the return flow, however, since part of the gross diversion returns as subsurface flow. We know also that the subsurface return flow does not always occur with the same timing as it enters the soil. It may be delayed for many days or even months. However, once again knowing what has been measured and estimated by the experts elsewhere along with our knowledge and measurements here we can estimate the return flow.

It is hardly necessary to note the need for further research into the measurement of irrigation water supplies.

The effect of these studies has been to increase the diversions for some projects and reduce them for others. The following recommendations are made to those concerned with the administration of water resources.

RECOMMENDATIONS

1. A standardization in the interpretation of all terms concerned with water resources in general and irrigation in particular in the three prairie provinces. In this regard the committee recommends the establishment of a glossary of water resources terms.

2. A standard form and method for the calculation of the amount of water required for irrigation used be established.

3. That the Blaney-Criddle method be accepted as the basis for calculating consumptive use for the present but that a periodic reassessment be made of the methods available.

4. That a continuing program of research be undertaken into all phases of irrigation water use with special emphasis on

   (a) plant consumptive use
   (b) farm efficiency
   (c) conveyance losses
   (d) return flow

5. That the method used for allocating water for all project by both the PPWB and the provinces concerned should be based on the net depletion of water from the stream i.e. gross diversion from the source of supply minus return flow to the source of supply.

6. That allocations made by both the PPWB and the provinces concerned be made on a ten year renewable basis in order to take into consideration changing conditions and the advancement in scientific knowledge and techniques.

7. That the allocation of water by gross diversions be discontinued but that the gross diversion should be recorded by the PPWB to ensure that the net depletion by any project does not cause a shortage to a more senior allocation downstream.

8. That the PPWB undertake, at some future date, a study of the allocation of water by provinces instead of the allocation by projects, to see if this would not provide a better means of control since basically the net depletion to the stream by the upstream province is the main concern of the downstream province. The quality of water and the regulation of flow also is of concern to the downstream province.

9. That the PPWB or the individual provinces approach the Federal Government to have a comprehensive study made by the appropriate agency into all phases of irrigation water use and that particular emphasis be placed on

(a) plant consumptive use
(b) farm efficiency
(c) conveyance losses
(d) return flow

10. That the existing network of meteorological and hydrometric stations be augmented to provide the information needed by the PPWB for administrative, planning and associated purposes.

11. That studies be undertaken to determine the water requirements in natural and artificial channels for the supply of water for stock and domestic use.

12. That the irrigation districts throughout the three provinces continue to place emphasis on the conservation and most beneficial use of water in their districts and that where necessary an education program be carried out to show the farmers the benefits of a more efficient program of water use.

13. That the provinces concerned investigate a means for obtaining more reliable records as to acreage irrigated, diversions, deliveries, waste etc. from some of the existing irrigation districts.

14. That the term "duty of water" be replaced by the term "net irrigation requirement" and that the use of the term "duty of water" be abandoned.

GENERAL

1. Summary
2. History of the Problem
3. Legal Aspects
4. Water Requirements for Irrigation
    (a) Plant Consumptive Use
    (b) Farm Efficiency
    (c) Conveyance Losses
5. Calculations

SUMMARY & RECOMMENDATIONS OF METHOD OF CALCULATIONS.

The amount of water required for irrigation purposes on the projects in the three western provinces has been computed, over the years, by using a duty of water calculated from experiments carried out on small plots by irrigation specialists in the early nineteen twenties. This information was transferred to the larger acreage of irrigation farms without consideration of the losses in efficiency which might occur. It is this decrease in the efficiency at the farm levels which is the major problem in calculating irrigation requirements today. At the time the present "duty of water" was proposed, and enacted the legislation of Alberta and Saskatchewan no future problems as to water supplies were foreseen and the method was adequate.

Irrigation expansion over the years along with a period of drought conditions has brought forward the need for a clarification and revision of the methods used in calculating the irrigation demands.

A clarification of the terms used in irrigation work appeared necessary. There is no general agreement in what a person means when they use irrigation factor, irrigation efficiency, duty of water, consumptive use, etc. It has been necessary therefore to first define these terms so that no doubt will exist in what is meant.

Secondly it has been necessary to check the methods used elsewhere so as to determine the best of the existing ways of calculating the water requirements of projects. One of the problems encountered was the lack of measured data on consumptive use. It was immediately evident that some other means would be necessary to arrive at a consumptive use figure for individual areas in the basin.

There are many methods used to calculate consumptive use i.e. the amount of water required for evapotranspiration but it appeared that only one of these, the Blaney-Criddle method, has been generally used in areas similar to our western prairies. Another factor in the use of an empirical formula was the availability of data to make a general calculation for the whole area.

The only two meteorological records generally available were for temperature and precipitation. This eliminated all the more sophisticated formulae but did not eliminate the Blaney-Criddle formula which is based on a knowledge of these two parameters. Checks were made with the existing consumptive use data and the formula chosen indicated a close correlation with the measured data.

Once the consumptive use data had been calculated it was then necessary to calculate the farm efficiency i.e. the amount of the water reaching the farm unit which actually is used by the plant in evapotranspiration. Here again data was not available and once again we turned to the United States and its various agencies for assistance in determining the percentage used. It is generally accepted that less than 50% of the water diverted into the farm unit is actually consumptively used.

The Senate report indicates that the U.S.D.A. estimate that by the year 2000 the average farm irrigation efficiency in the areas adjacent to the prairie provinces will be approximately 60%.

It was with this information and a general knowledge of present conditions that the farm irrigation efficiency was set at 60%.

Once the farm delivery requirements were calculated for a typical farm unit, then all that was necessary in order to determine the gross diversion requirements was to add in the conveyance losses. These losses indicate the losses encountered in delivering the water from the point of diversion to the farm unit including both canal and reservoir losses. Return flow information indicates, also, that estimated percentages which were formerly used may be too low and these have been raised in order to bring them into line with more recent information.

It must be emphasized, however, that the need for further research into consumptive use, farm efficiency, conveyance losses, return flow and wastes is urgent and that the assumptions made in this study should only be used until further research gives a more accurate estimate.

It is our opinion that the P.P.W.B. is only concerned with the depletion from the stream and in the quality of the water returned to the stream. Therefore we would be of the opinion an allocation should mean the net depletion to the stream measured at a point below the project with due allowance for the surface and groundwater inflow from the incremental area between the two measuring points, not due to waste water or return flow i.e. possibly the interprovincial boundary. The gross diversion should be recorded only as information to the board and not as the controlling figure. This is the method used in other similar types of inter-area pacts regarding streams, probably the best example being the Colorado River pact where each State is only concerned that a certain amount of water passes a point downstream.

This study is based on the average conditions and as a result in dry years after full development some rotation and rationing will be necessary. However we feel that this may be necessary and desirable to assure the best and most beneficial use of the water supplies available.

RECOMMENDATIONS CONCERNING CALCULATION OF WATER REQUIREMENTS.

1. That the Blaney-Criddle method be used to compute crop consumptive use.

2. That the estimate of 60% efficiency be used to calculate farm efficiencies.

3. That conveyance losses be calculated on the basis of information from each project.

4. That the gross diversion be made up of the consumptive use, farm losses and conveyance losses.

5. That the project consumptive use be determined by taking the estimated return flow from the gross diversion.

6. That further studies be taken to improve the accuracy of these studies and that the allocations for these projects be reviewed every ten years in the light of these studies.

7. That a need exists for further meteorological hydrological stations, evaporation pans, until some better means of measuring evaporation should be established at least at all class "A" stations.

8. That steps be taken to study and develop a better method of measuring return flow and the percentage of the return flow which occurs as groundwater.

9. That the irrigation districts continue to take all steps necessary to minimize their waste of water and to improve their methods of delivery and operations.

HISTORY OF PROBLEM.

The question of "how much" water is required to irrigate a piece of land on the western prairies has long been under discussion. Originally the duty of water was set at 2 acre feet/acre. This was considered excessive and in 1913 experiments were started at Coaldale, Alberta to find out the minimum amount of water which would produce maximum crop growth. These experiments were carried out on small plots and were undertaken to determine;

1. The amount of water required to produce the maximum yield of a specific crop when grown under varying conditions of soil fertility, soil texture and climate.

2. The proper depth of water to apply per irrigation for different soil types and for different crops.

3. The relationship between the "irrigation head" and the distance between the distributing ditches.

4. The seasonal water requirements of various crops, or the time when irrigation water should be applied.

5. The amount of water supplied to, wasted from, and used on the farms of the typical irrigation project.

The project was expanded in 1914 to 1917 to include stations at Strathmore, Ronalane, Gleichen, and Brooks. As a result of this work the duty of water was reduced to 1.5 Ac.Ft./Acre.

In 1930 W. H. Snelson, Senior Irrigation Specialist for the Department of the Interior for Canada published a report "Irrigation Practise and Water Requirements for Crops in Alberta" which has over the years been used almost as an "Irrigation Bible" in Alberta. The report summarized the result of the experiments conducted in Alberta during the period from 1913 to 1928. In his report he states that the amount of water a plant will transpire depends on;

(a) The amount of water held in the soil occupied by its root system.

(b) The amount of energy, as light and heat, received from the sun.

(c) The relative humidity of the surrounding atmosphere as influenced by winds, rain, surface evaporation and shades.

(d) The area of leaf surface and the extent of its moisture absorbing root surface.

(e) The fertility of the soil or the concentration of soil solution in available nutrients.

These experiments were carried out at Brooks, Ronalane, Strathmore and Coaldale. The water supply was measured at the plot or farm headgate. The effective precipitation was taken into consideration.

The results were given as to the amount of water a crop would use in maximum production. The irrigation water was measured at the farm headgate and to this was added the effective precipitation and any soil moisture change during the growing season.

The results were as follows:

Brooks	Mean Depth of Water Used
Alfalfa	36.4 inches
Peas	24.6 "
Wheat	23.8 "
Oats	22.3 "
Barley	20.9 "
Flax	20.4 "
Potatoes	19.8 "
Grass	19.6 "
Beets	19.2 "
Alfalfa Seed	17.0 "
Corn	16.4 "
Ronalane	
Peas	28.4 "
Wheat	26.4 "
Oats	21.8 "
Barley	21.0 "

The mean depth of water used included percolation, evaporation and transpiration. These are the average figures for the experiments carried out on three types of land, i.e. high, medium and low fertility.

Since that time experiments have been continued into the use of water by crops at various locations in the area to determine the correct amount of water to use to get maximum production without waste.

It was however after these original experiments that our present duty of water was decided. Since there is no way of knowing the losses due to percolation etc., we cannot really estimate the plant consumptive use.

The duty of water was defined as the amount of water required to be supplied by artificial means to give maximum crop production with water measured at the plot headgate.

It is particularly to be noted that the "duty of water" was determined on small controlled plots and then applied to the larger farm units without any allowance for the increased losses which would occur due to irrigation of the larger unit. In other words they assumed that the irrigation efficiency of an average irrigation farm was the same as a small levelled plot with complete water control. Since the 1920's this duty of water of 1.5 feet per acre has been used for all of Alberta and Saskatchewan's computations for irrigation requirements.

Since both Alberta and Saskatchewan's license gives the licensee the right "to take and keep possession of the said quantity of water" it is obvious that this means that the license is on the basis of net depletion from the stream.

Gross diversions have only been necessary in so far as licensing is concerned to insure that the quantity of water is available at the point of diversion. It was with this background that Alberta's request was made for water for the existing projects in Alberta in 1949.

It was not until expansion of the St. Mary Milk River project, the Bow River project that a dry period occurred which brought to light the fact that many districts were exceeding their allocations.

In 1962 Alberta requested a review of its existing allocations with a view to having them increased in line with the diversions which were then being made by the various districts. It was at that time this committee was formed to investigate the problem.

LEGAL ASPECTS.

"Is the Prairie Provinces Water Board concerned with the gross diversion for a project or are they basically interested in allocating water on the basis of net depletion to the stream by a project"? This is the question that must be settled by the Board prior to any change in allocations. Obviously from previous meetings no agreement exists. In fact there is some disagreement as to whether the present allocations are for gross diversions or for consumptive use. This is true to an extent, as far as Alberta is concerned, even in the correspondence with the individual districts prior to Alberta's original request for an allocation.

In the Colorado compact between the various States in the United States along the Colorado river the method used in apportioning the water is on the basis of net depletion from the stream. The St. Mary-Milk River treaty uses the same basis i.e. net depletion from the stream.

This appears sound since the downstream user whether it is a State, a project or an individual is only interested in seeing that sufficient water is available downstream to satisfy the demand and to see that the water depleted from the stream by a project is put to beneficial use.

In our study we also contacted 21 States in the United States where irrigation is practised. While most of the States have the amount of water allocated to a project settled on the basis of availability and beneficial use, there is no set method of measuring this amount of water. In some States the court adjudication sets the gross diversion as the controlling factor, in others, the net depletion from the stream is the controlling factor. In some States they have statutory control of the amount of water a project may divert.

Nebraska limits the amount by legislation to 1 c.f.s. per 70 acres measured at the point of delivery to the farm unit. They also set the maximum gross diversion from a stream at 3 acre feet per acre. Washington not only sets the farm delivery, but also sets the maximum instantaneous rate of diversion. West of the Cascades they regulate the water as follows:

30" to 48" farm delivery

4 Ac.Ft./Ac. maximum farm diversion

0.02 cfs/acre maximum instantaneous rate which if diverted throughout the season amounts to 6 Ac.Ft./Ac. gross.

In other States no regulation is presently in effect. In Montana the control of the water is at the farm headgate since each individual farmer pays for the water he uses. They must therefore measure his water at the point of delivery to the farm unit.

In some States they recognize return flow and then the control is on net depletion from the stream. In California for example a license may divert all the water from the stream even though a prior license may exist downstream providing the return flow from the upstream project is available downstream to satisfy the prior license.

In Nevada the opposite is true. The return flow from a project is not recognized and hence the gross diversion is the controlling factor. The State does not generally limit the amount of diversion but they do control the area to be irrigated. The acreage and the amount of water allocated by the courts are on the basis of farm deliveries. It appears that no set policy of licensing or control exists in the area but in the majority of the States licenses are based on farm delivery. However in all cases it is necessary to know the gross diversion requirements in order to operate and maintain control of the water resources. It is necessary to know sufficient water is available to satisfy the projects demands

and hence the gross diversion and the gross diversion rates are important to those operating the projects.

Both Alberta and Saskatchewan presently have a licensing system based on net depletion from a stream and this appears to be the natural method to use. Any system that is used in the allocation of waters by the Interprovincial Board should match with the system used by the majority of its members. The committee recommends therefore that in the future that all allocations be based on the net depletion from the stream so that the allocation made by the Prairie Provinces Water Board will be the same as that approved by the provinces concerned.

The committee also recommends that gross diversion also be recorded but only for the purpose of knowing the amount of water required in the stream at the point of diversion. This will then mean that the wording in the Alberta-Saskatchewan licenses "to take and keep possession of" will be correct since any water not returned to the stream is in effect "taken and kept possession of".

It appears that this is the only sound way to administer the resources. Once a project is considered a beneficial use, all that anyone either in the administrative end or on the stream downstream of the project is concerned with is

(a) is there sufficient water in the stream to satisfy those downstream of the project.

(b) is the water being depleted from the stream being put to the most beneficial use possible.

(c) is the water chemically changed in such a way as to affect those downstream.

(d) that any upstream regulation does not adversely affect the timing of water supplies to meet the prior needs downstream.

Admittedly, those operating a project and those in the administration field must know the gross diversion requirements. However, the administrator only needs this to insure the water is available at that point and the project manager to know how much he must take from the stream. Both of these appear to be internal problems and not necessarily those of the Water Board. We would therefore recommend that the allocation of water be based on net depletion from the stream but that the gross diversion also be recorded but for information purposes only.

WATER REQUIREMENTS FOR IRRIGATION PROJECTS.

The problem of deciding the amount of water required for a project is a complex one made much more difficult because of the lack of data on which to base our calculations.

The calculations can be broken down into four main parts.

1. Water required for plant consumptive use.
2. Water required to supply the losses encountered at the farm level i.e. deep percolation, waste and evaporation.
3. Water required to supply the losses incurred in carrying the water from the point of diversion through the canals and reservoirs to the point of delivery to the farm unit.
4. The water returned to the stream or adjacent streams for use downstream.

The total requirements or gross diversion to a project is the sum of the plant consumptive use, farm efficiency and the conveyance losses.

The net depletion from the stream is the gross diversion minus the return flow.

Plant Consumptive Use.

The water used by a crop may come from any one of four sources:

1. Precipitation
2. Soil moisture
3. Groundwater
4. Irrigation water

To make an estimate of the water required for irrigation a person needs to know the actual consumptive use of the plants together with the water available due to precipitation, soil moisture and groundwater. Having these factors all available he can then determine the irrigation water requirements of a crop.

The determination of consumptive use is a difficult and complex problem. To simplify the calculation various empirical formulae have been proposed. These formulae all take into account one or more of the climatic factors. These climatic factors, temperature, precipitation, evaporation, relative humidity, radiation, hours of sunshine, etc. are generally considered to have the greatest effect on plant growth and plant water requirements. Other factors affect plant water requirements are soil, topography and water supply. While some of these factors have a major effect on the method and timing of irrigation they are considered to have a more minor effect on the total plant consumptive use. It is to be noted that all formulae which have been developed to date require certain constants which are purely empirical, to correct for certain plant growth processes and physiological characteristics.

The scientific equipment required to assess the natural phenomena of plant growth has been complex and the field operation difficult. Progress has been made in solving the mysteries of plant growth but much remains to be done before a truly scientific formula based on the basic pretexts for consumptive use will be found. In the meantime these empirical formulae must be used. When one considers the lack of knowledge and the assumptions that are made with regards to:

(a) farm irrigation efficiency

(b) waste

(c) conveyance losses

(d) return flow

The accuracy obtained in the use of these empirical formulae far exceeds the accuracy of the other items required in calculating the irrigation water requirements. In fact the need for further research into the measurement of farm efficiency, project efficiency, return flows, far exceeds that of consumptive use.

In using these empirical consumptive use formulae it is necessary to use judgment and any information available to select the formula best suited to the area under consideration which will use the measured meteorological data available in the area. It is all very well to say a certain formula is better than the rest, but, if no data are available then the formula is of no real value and another one will have to be used.

Methods of Calculating Consumptive Use.

1. Actual Measurements
2. Blaney-Criddle Method
3. Lowery Johnson Method
4. Penman Method
5. Thornewaite Method
6. Oliver Method
7. Hargreaves Method
8. Atmometer Method
9. Other Methods

1. Actual Measurements.

There are three types of Actual Measurements made.

(a) Lysimeter

(b) Field plots

(c) Groundwater fluctuations

(a) A lysimeter is defined a structure containing a mass of soil designed to permit the measurement of the water draining through the soil. Individual crops are grown under controlled conditions in these lysimeters and the measurements collected yield the actual consumptive use of water by the plants. These lysimeters installations are costly and are rather scarce. They are usually found in conjunction with an Agricultural Research Station or a University.

(b) Field plots have crops planted under normal conditions and the measurements are made of the water added to the soil by rainfall or irrigation, the water which runs off the field plot and the change in the soil moisture conditions. The net result is a measure of the consumptive use.

(c) Groundwater fluctuations. A measurement of the change in groundwater levels, along with a measure of any water added to the soil, or lost by runoff can give a measure of the consumptive use of the vegetation in a particular area. The groundwater table must be reasonably close to the surface to make this method applicable.

2. Blaney-Criddle Method.

The Blaney-Criddle method is based on the assumption that the consumptive use of water by a particular crop varies.

(a) as the type of crop grown
(b) the temperature
(c) the length of the growing season and
(d) the monthly percentage of annual daytime hours

Expressed mathematically:

$$U = KF = \sum kf$$

where U = consumptive use of water by the plant in inches

K = an empirical seasonal coefficient based on the type of crop and the length of the growing season

F = the sum of the monthly consumptive use of factors (f) for the growing season

$$f = \frac{txp}{100}$$

f = the monthly consumptive use factor

t = temperature in Fahrenheit

p = the monthly percentage of daytime hours at a particular latitude for the period under consideration.

Since in many areas scientists have measured the consumptive use for many types of crops it is possible to calculate the factor K (or k) for many areas

by $K = \frac{U}{F}$ or $k = \frac{u}{f}$

In other areas, where no actual consumptive use data is available this constant must be estimated from the data available at other stations.

The value of K (or k) for particular crops has been found to vary within a certain limited range and hence the assumption of a reasonable figure is possible.

The value of p is taken from a standard set of tables which vary only as the latitude of the station. Hence the only variable is temperature (t) and this is available in most areas. In areas where temperature records are available the formula is easily solvable with a minimum amount of assumption. This formula is the one generally used in the Western States by the United States Bureau of Reclamation as well as the State of Montana, North Dakota and Idaho. The Saskatchewan Government also has used this formula in its South Saskatchewan project considerations. This method is also based on the use of water by large irrigation projects similar to that we are considering and on plot or lysimeter data.

3. Lowery-Johnson Method.

The Lowery-Johnson method has been developed on what is defined as "Valley Consumptive Use". This term is defined so as to include all of the valley or basin area in the consumptive use determination. The consumptive use calculations, the water requirements for a project includes the uncropped area as well as the cropped area. Valley consumptive use, is therefore, the difference between the annual inflow into a valley (precipitation, surface and subsurface water movement into the valley) and the total outflow from the valley (surface and subsurface) with appropriate corrections for changes in surface and subsurface storage. It does not include deep percolation losses.

The method resulted from a correlation of various climatic factors with measured consumptive use. Temperature, precipitation, wind and humidity were considered in the study. The study concluded that the following formula best represented the conditions in the areas for which the survey was taken.

$$U = 0.8 = 0.156\ F$$

where U = consumptive use in Ac. Ft.

F = effective heat in thousands of degree days during the growing season above 32 F.

The method was developed and has been generally used in the south central part of the United States. It is used in that area by the United States Bureau of Reclamation. It is generally considered more applicable in the relatively more humid areas.

4. Penman Method.

The Penman method was developed in England and takes into consideration most of the climatic factors affecting consumptive use.

The following formulae are used

(1) $$H = R_a\ (\ell - r)\ \ (0.18 + 0.55\ n/N) - \sigma T_a^{\,4}\ \ (0.56 - 0.092 \sqrt{ed})$$
$$(0.10 + 0.90\ n/N)$$

(2) $$Ea = 0.35\ (e_a - e_d)\ \ (1 + 0.00098\ u_z)$$

(3) $$Et = \frac{\Delta H - 027\ E_a}{\Delta - 0.27}$$

where H - daily heat budget at surface in mm H_2O/day

Ra = mean monthly extra terrestrical radiation in mm/H_2O/day

r = reflection coefficient at surface

n = actual duration of bright sunshine

N = maximum possible duration of bright sunshine

σ = Boltzman Constant = 2.01 x 10.9 mm/day

$\sigma T4_a$ = mm/H_2O/day

e_d = saturation vapor pressure at mean dew point (i.e. actual vapor pressure in air) mm hg

E_a = evaporation in (mm) H_2O/day

e_a = saturation vapor pressure at mean air temperature in mm hg

U_2 = mean wind speed at 2 meters above the ground (miles/day)

$U_2 = u, \times \frac{\log 6.6}{\log h}$ to correct wind speed at other heights to 2 meters

u = wind speed in miles/day at height h meters

E_t = evapotranspiration in mm H_2O/day

This formula is considered by many as the most desirable to use since it contains most of the climatic factors affecting crop growth and water use but due to the fact that all the data is seldom available it is not generally used.

Computation sheets have been set up by the author to provide for easier calculation.

5. Thornewaite Method.

During the 1930's C.W. Thornewaite developed a formula to classify climate. He found that an expotential relationship exists between the average monthly temperature and the mean monthly consumptive use.

The formulae used are as follows:

(1) $$i = \left(\frac{t}{5}\right)^{1.514}$$

where i = monthly heat index

t = temperature in C

(2) $e = 1.60 \left(10 \frac{t}{I}\right)^a$

where e = potential evapotranspiration

t = mean monthly temperature in C

I = heat index for 12 monthly periods

$a = 0.000000\,675\,(I)^3 - 0.0000\,771\,(I)^2 + 0.01792\,(I) + 0.49230$

A graph is used to determine the monthly heat index from the temperature in °C and to determine the potential evapotranspiration from the yearly heat index and the mean temperature °C. This method has been used in Dr. Laycock's study of aridity in the Prairie Provinces for the P.P.W.B.

6. Oliver Method.

In 1916 Mr. H. Oliver of England made a study of Irrigation and Climate and as a result of this study he proposed the following formula for universal use.

$Cu\,\emptyset = C\,W\,\emptyset = M_p/L$

where $Cu\,\emptyset$ = the basic water requirements in mm/day for a crop soil unit at latitude $\emptyset$

Consumptive use.

C = the average depression of the wet bulb in C for the particular month obtained either from direct readings or from averages of temperature and humidity readings at station $\emptyset$

$W\emptyset = L^o/{}^2L$ = the cyclic (radiation/latitude) factor for the particular month

M_p = the free water surface evaporation in mm/day, from a standard tank at latitude $\emptyset$

L = monthly variation of the ratio of the total radiation to the vertical radiation to the mean.

In actual operation the formula

$Cu\,\emptyset = 0.03936\,C\,W\,\emptyset$ is used

$W\,\emptyset$ has been calculated and a table is supplied for ease of calculation

C is calculated from records and the result and consumptive use is in inches. This is a relatively new formula but Mr. Oliver in his book goes to great lengths to prove it is applicable at any point where wet bulb or humidity readings are taken.

If the free water evaporation is available then the formula

$Cu\,\emptyset = 0.0396\,M_p/L$ in inches

L is available from tables and hence the solution is relatively simple.

7. Hargreaves Method.

The Hargreaves method is based on the following assumptions:

(1) The evaporation of water is a physical process and can be computed.

(2) An empirical relationship exists between the computed evaporation and the consumptive use of water by plants.

The climatic data required in this method are the mean monthly temperature, mean monthly relative humidity at noon, and a daytime coefficient dependent on latitude.

In this formula the consumptive use is assumed to vary directly with the evaporation potential.

The formula:

$U = KE = \sum ke$ in inches

where U = the consumptive use of the crop in inches for a given period

E = the sum of the monthly evaporation (e) for the period

K = the seasonal empirical coefficient depending on the particular type of crop grown

$e = cd\ (+ - 32)$

where C = climatic factor depending on humidity and to a minor degree wind movement

d = is the monthly daytime coefficient depending on latitude

t = mean monthly temperature in ^{o}C

This formula has received some praise but not too much general use since it requires meteorological data that is not available at all locations. It can be used with evaporation pan data to give a consumptive use.

This formula, with an addition to give consideration to wind velocities and with amended constants is favored by Mr. W. L. Foss.

The amended formula suggested by Mr. Foss

$e = 0.68\ d\ (0.38 - 0.0038h)\ (0.23 + 0.073\ Vw)\ (+28)$

where e = evaporation in inches per month

d = percentage of daytime hours for the month

h = relative humidity at 1730 hours

Vw = wind velocity in mph

T = temperature in ^{o}F

and $U = KE = \sum ke$

k - empirical constant dependent on crop growth

Mr. Foss also notes that on any area with a $\frac{R}{U}$ of 50% or more wheat farming would be successful on a long term basis. Where R/U = 45 to 50% moderate success in wheat farming would occur and where R/U = 40 to 45% farming would be hazardous and where R/U is less than 40% crop failure is inevitable. R is the rainfall during the growing season.

This formula, while usable in this area, has the disadvantage of requiring data that is avilable at very few stations.

8. Atmometer Method.

In the last few years the use of atmometers in the calculation of consumptive use has received some consideration. The atmometer measures the drying ability of the air or the evaporation potential of the air. It does not measure evapotranspiration so a constant is used (0.0034 inches/cu. cm) to convert this latent evaporation to potential evapotranspiration.

The Black Bellani plate atmometer is the best known instrument and it gives a simple means of estimating potential evapotranspiration or consumptive use.

Considerable more experimentation is necessary before this instrument could be accepted but if it proves successful it would provide a cheap and rapid means of calculating consumptive use. This would be especially useful on a daily water balance for a crop.

9. Other Methods.

Many other methods, all of which are empirical in nature, and most of which are based on meteorological data have been proposed. The ones listed above are those most commonly accepted and used in different areas throughout the world.

Choice of Method.

In the prairie provinces the only meteorological data available generally throughout the area is temperature and precipitation. This means that any formula we accept must be based on these two factors.

The empirical formulae available using this data only are:

1. Thornthwaite
2. Blaney-Criddle
3. Lowery-Johnson

The only station available with sufficient consumptive use data and the meteorological data to check these and other formulae was Taber.

At Taber consumptive use data has been calculated for some years. The averages are from the report by Krogman and Hobbs and are as follows:

TABER-VAUXHALL

Alfalfa	25.5 inches
Grass	23.6 "
Sugar Beets	21.5 "
Potatoes	19.9 "
Soft Wheat	19.4 "
Hard Wheat	18.2 "
Oats	16.1 "
Barley	16.1 "
Flax	15.2 "
Canning Corn	15.2 "
Field Corn	14.7 "
Tomatoes	14.4 "
Canning Peas	13.4 "

Table shows the result of calculations made using the various formula available. Only the Blaney-Criddle formulae used the crop coefficients for individual crops.

The average measured consumptive use was 20.5 inches. The Blaney-Criddle method with tailored coefficients gave 20.5 inches. The next closest was the Hedke formula which gave 20.42. It is to be noted also that evaporation pan data with a correction coefficient of 0.75 gave 20.32 inches as the crop rerequirement.

We must note that the figures used in the decision of the method to be used and in the calculations are the average temperature and precipitation. This may result in dry years after full development of rationing and rotation. However this will still assure crops in these years when other areas have crop failures.

In any event the use of the 10 year renewable allocation would allow for reconsideration of these requirements at a later date.

As a direct result of this and other studies and also due to the general acceptance of the method by the United States Bureau of Reclamation, U.S. Dept. of Agriculture and the U.S. Army Engineers as well as the States of Montana, Idaho and North Dakota and the Province of Saskatchewan we have decided to accept the Blaney-Criddle method for this study. This does not mean it is any better than some of the other methods but with the information available it gave us a reasonable consumptive use figure for all areas concerned. The fact that only temperature and precipitation were the only meteorological data available in sufficient quantity to give us the necessary data for coverage of the three provinces certainly did not hinder our decision to accept this method of calculation.

CONSUMPTIVE USE

Station	Vauxhall		Crop	Alfalfa	Rel. Humidity (Lethbridge)	Measured Cons. Use	Thornthwaite	Lowry Johnson	Blaney Criddle	Hargeaves	Hargreaves (Foss)	Oliver	Hedke	Penman	Evap. x.75
Month	Temp.	Pptn.	Evap.	Sunshine											
May	51.8	1.62	5.22	249	50		2.88		3.20	3.60	1.54	3.30		5.89	3.91
June	58.5	2.08	5.58	290	55		3.90		5.67	4.48	4.07	3.47		6.00	4.18
July	65.8	1.62	6.49	330	49		5.12		7.23	6.35	6.87	4.94		7.56	4.87
Aug.	62.8	1.33	5.92	271	51		4.43		5.63	5.27	4.95	6.03		6.29	4.44
Sept.	53.1	1.32	3.89	222	53		2.41		2.25	2.87	1.42	3.48		3.33	2.92
						24.1	18.74	17.2	23.98	22.57	18.85	21.22	20.42	29.07	20.32
	GRASS														
May									2.67						
June									4.41						
July									6.87						
Aug.									6.25						
Sept.									2.25						
						22.55			22.45						
	GRAIN														
May									1.07						
June									3.78						
July									6.51						
Aug.									5.63						
Sept.															
						17.0			16.99						
	SPECIALTY CROPS														
May									1.07						
June									4.41						
July									5.78						
Aug.									5.94						
Sept.									1.35						
						18.4			18.55						
						Average 20.5			Average 20.49						

Farm Irrigation Efficiency

A certain amount of uncertainty exists, in respect to what is meant by farm irrigation efficiency. In Alberta in calculating irrigation requirements an irrigation factor of 80% has been used. This has at times been mistakenly called an irrigation efficiency.

The irrigation factor as used by Alberta meant that 80% of the total irrigable acreage would be irrigated in any one year. Since in the final development of a project there would be no reason to leave any land idle or in summer fallow we recommend that this term as well as its use in calculating irrigation requirements be dropped. This would mean that the water requirements for a project would provide for the irrigation of every acre in its irrigable area in every year.

In its place in our calculations we recommend the use of "farm irrigation efficiency," which means the percentage of the water delivered to the farm headgate that is stored in the soil profile for use in plant growth.

The losses considered at the farm level are waste and deep percolation and one of the difficulties in the computation of farm requirements is the estimation of these losses.

Farm waste is dependent on many factors among which are topography, soil, type of crop grown, the availability and cost of water and last but not least the ability and attitude of the irrigators. These are mainly the same factors which affect deep percolation.

In the report by the Bureau of Reclamation on the "Use of Irrigation Water" they mention the need for further scientific investigations in this field. It is interesting to note that in this report on projects operated by the Bureau the average farm waste and deep percolation represents approximately 40% of the diversion or expressing it as a farm irrigation efficiency, this is 60%.

Of 20 projects reporting 4 have a farm irrigation efficiency of 70% or better, 8 have a farm irrigation efficiency of 60% or better, 14 have a farm irrigation efficiency of 50% or better. The highest efficiencies are in areas where the crops and the water available are of the greatest economic value.

In the 1960 U.S. Senate Report on Water Resources activities the U.S. Dept. of Agriculture noted that in 1954 none of the areas where irrigation is practised in the United States showed a farm irrigation efficiency of greater than 60%.

In the area adjacent to Canada's Prairie Provinces they showed that the Upper Missouri Basin, which we most closely resemble, will probably have an efficiency of 60% by the year 2000. This increased efficiency will result from:

(1) more efficient farmer irrigators
(2) better land preparation and levelling
(3) greater value being placed on the use of water
(4) economic pressure

We must note that to date no item has ever been included in Alberta calculations to take care of the losses in applying water to the soil. This is due to the fact that when the "duty of water" studies were made early in this century the measurements were made on small plots and the water reaching the soil as rainfall or applied as irrigation was measured as was the surface return flow. Some checks were made on the soil moisture conditions. The difference between the inflow and the waste water minus the rainfall was considered to be the "duty of water" for that crop or area.

When the information collected at that time was used it was transferred from the small, level, highly controlled test plots to the larger farm units without any allowance for the losses which would occur due to normal irrigation practises on the average irrigation farm unit. It is in this regard that the greatest error occurred. It meant that if the duty of water prescribed was to be sufficient, that the farm unit must be operated with the same care and efficiency as the test plot. This was economically unsound and hence a greater amount of water than the originally proposed duty has become necessary.

Therefore, in our calculation we should:

(a) abandon the use of an irrigation factor
(b) incorporate into our calculations a farm irrigation efficiency factor. At least for the present, and until someone proves that this is not sound we should accept and use 60% as the farm irrigation efficiency. This being the figure we should attain by the year 2000, or by the time these projects would be fully developed. In the meantime the lower farm irrigation efficiencies would be covered by the fact that our irrigable acreage is not presently all irrigated in any one season. This means water is available at a greater quantity per acre until full development takes place.

Conveyance Losses

It is a generally accepted fact that approximately 1/3 of the water diverted to an irrigation project is lost in conveying it to the land. Another 1/3 is lost because it percolates too deeply or some runs off after reaching the farm headgates. The importance of these losses to an irrigation system cannot be

over emphasised.

Conveyance losses are those losses that occur in transporting the water from the point of diversion to the farm headgate of a system.

They include:

1. Canal losses
2. Reservoir losses
3. Waste

1. Canal Losses.

Canal losses occur due to:

(a) Evaporation
(b) Seepage
(c) Waste
(d) Evapotranspiration

(a) Evaporation from the canal system is considered of a minor nature since it generally represents less than 1% of the water diverted through the canal system.

(b) Seepage represents the major source of water lost in the canal system. Seepage is dependent on the material through which the canal passes and the hydraulic properties and physical condition of the canal system. The magnitude of these seepage losses is important both from the point of view of the canal losses and the damaging effect it will have on farm lands which become seeped.

The U.S. Bureau of Reclamation notes that seepage varies directly with wetted area, head and permeability coefficient which has a wide range of values depending on the characteristics of the soil and its current condition.

The most reliable method of estimating conveyance losses is a reference to losses on constructed canals of similar size in similar soils.

(c) Waste. It is virtually impossible to operate a canal system without waste. These losses include leakage past gates, excess diversion, canal breaks, failure of a user to accept delivery due to holidays, rainfall, etc. and water required to provide deliveries. The amount of waste is largely dependent on the availability of supplies and to economics considerations.

(d) Evapotranspiration is due to vegetation along the canal banks and natural channels. This can represent a minor loss if kept under control and conversely it can become of relatively major importance if vegetation is allowed to grow unchecked.

2. Reservoir Losses.

These losses consist generally of two items, seepage and evaporation although riparian vegetation may enter the problem in a minor way.

The measurement or estimation of the losses due to evaporation is relatively easy to calculate i.e. the surface area times the evaporation minus the precipitation. An estimate of the evaporation can be obtained from meteorological reports as can the rainfall on the area.

The seepage from the reservoir is difficult to measure and generally if actual measurements are made the two factors are lumped together in the term reservoir losses.

3. Waste.

This is water run through the canal system or reservoir which is allowed to pass down spillways and drains back to the rivers and streams. Theoretically a district could operate without waste in its conveyance system but practically this is impossible. Rainstorm, excess diversions, structure leakage, and human vagaries all lead to waste. It is virtually impossible to deliver exactly the correct amount of water to the last delivery and have none left over to waste. All these factors are generally included in one item called conveyance losses or distribution system losses. In the Bureau of Reclamation report the 21 projects listed in the United States have losses varying from 3.8% in a completely lined system to 52.5% for a system with 5.3 miles of unlined canals. The average losses were 37%.

In the Senate Water Resources report the Dept. of Agriculture estimates the losses 1954 to range between 40 and 60% and that by the year 2000 these losses will range between 30 and 50%.

In the Missouri basin which most closely resembles our area the 1954 figure was 60% and the estimate for the year 2000 is 50%.

In Alberta the following losses have been used:

Western	30%
Eastern	40%
BRD	40%
St Mary Milk River	30%
L.N.I.D.	23%
U.I.D.	20%
Mountain View	28%
Leavitt	25%
Aetna	35%
Macleod	25%

and are generally accepted as being reasonable for the areas concerned. These conveyance losses percentages will be used in our calculations. Further investigation is needed to check these values and determine those for other areas where irrigation may be practiced.

Return Flow

The importance of return flow is only now being realized. The measurement of return flow, or its estimation is difficult. Return flow is the water which is not consumed in evaporation or transpiration on an irrigation project and returns to some surface stream.

The increased flows which may result from the increase in runoff which may occur after lands are brought under irrigation should be considered as part of return flows. The determination of return flows, with as much accuracy as possible is necessary in order to estimate the net depletion from the stream by the project. Since the only responsibility of the project operator in diverting water is to see that the prior licenses downstream are satisfied before they take their licensed amount, an accurate determination may allow them to divert a greater amount of water from the stream and be able to rely on the return flows increase in the stream flow so as to provide the required amounts downstream.

It requires some years after a new project is in operation before the return flows from a project are stabilized. Return flows are made up of two components.

1. Surface Return Flow
2. Subsurface Return Flow

In Alberta the surface return flows have been measured by the Federal Department of Water Resources. No measurements have been made of the subsurface return flows.

Even the surface return flow measurements create a problem since with the present instrumentation it is virtually impossible to obtain a value for any of the smaller wasteways which contribute to the return flow. Thus these return flow records show only part of the surface return flow and practically none of the subsurface return flow. We must note that they do include the major portion of the surface flows.

In order to try and arrive at the net depletion from the streams, additional stations have been set up on the Red Deer, Oldman and Bow Rivers to obtain additional data. It is hoped by using the data from these gauges that more realistic measure of the return flows will be possible. In former studies the return flows of the various Alberta projects have been estimated as follows by Ben Russell.

Western	15%
Eastern	15%
Bow River	15%
SMRD	15%
LNID	15%
U.I.D.	25%
Aetna	30%

Leavitt	30%
Mountain View	30%
Macleod	20%

The return flow measured in the Return Flow studies conducted by the Federal Water Resources show the measured return flow from the Western Irrigation District to average 40% of the water diverted, the Eastern Irrigation District 25% and the Bow River project 20%.

If we correct these figures to indicate all surface return flow, whether measured or not and then add a percentage for subsurface return flow the estimated return flows would be:

Western Irrigation District	50%
Eastern Irrigation District	40%
Bow River Project	35%

In addition to this the other projects in Alberta have no measured return flow information available so that these projects return flow must be from comparison with other areas and a general knowledge of the return flow problem. We have estimated these as follows:

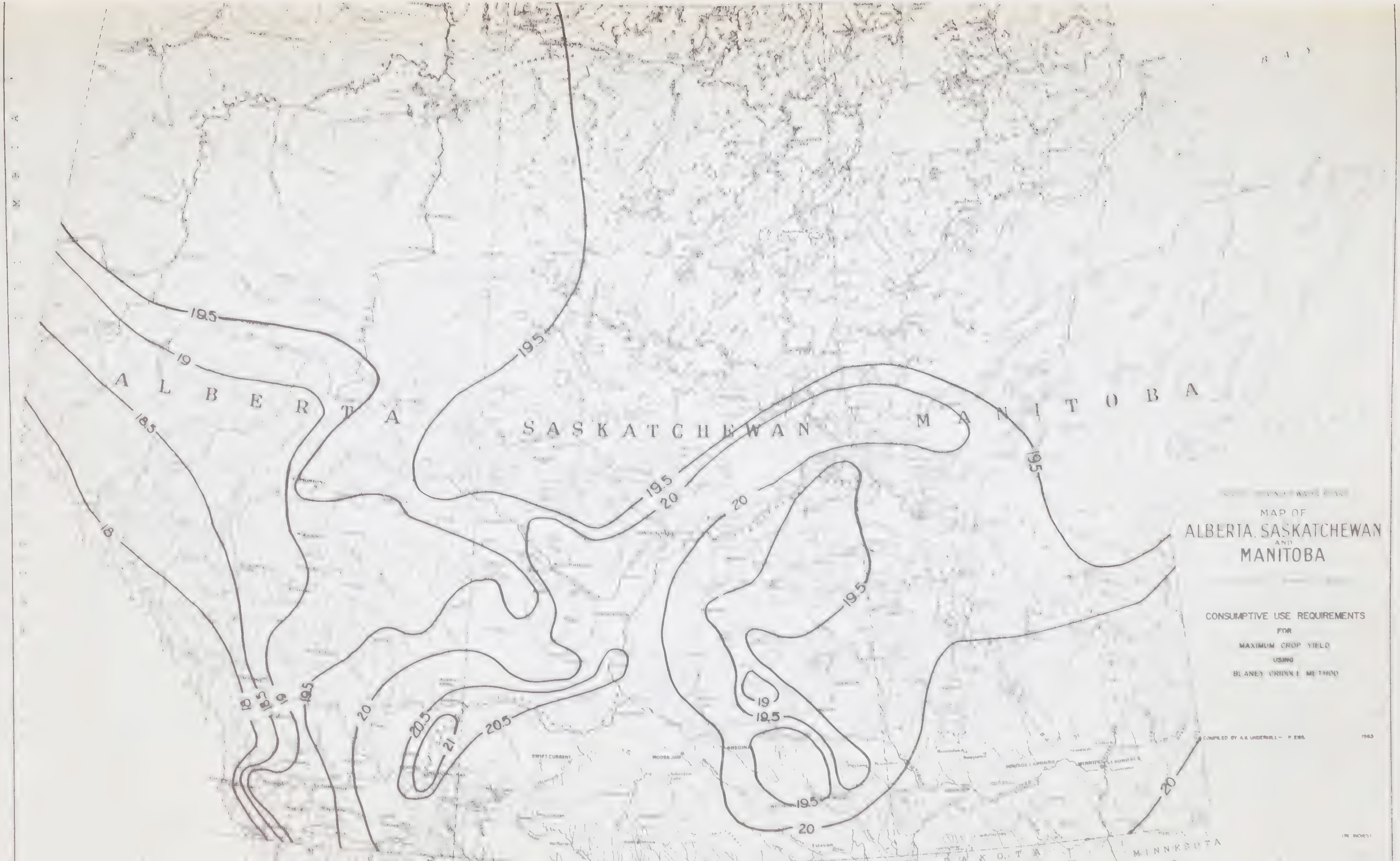
St Mary-Milk River Development	35%
Lethbridge Northern Irrigation District	35%
United Irrigation District	40%
Aetna Irrigation District	40%
Leavitt Irrigation District	40%
Mountain View Irrigation District	40%
Macleod Irrigation District	40%

These you will note are considerably higher than those Ben Russell proposed in his submission to the P.P.W.B. The changes have been made in line with the measurements which have been made since that time which indicates these estimates, which were made on the basis of surface return flows only, were much too low.

It is also noted here in checking the flows of the Red Deer River, there are indications that considerable inflow occurs in the section between Drumheller and Bindloss which probably can be attributed to unmeasured irrigation return flow.

In the year 1959-60 studies indicate even with deducting the measured return flow some 161,000 acre feet that cannot be accounted for. This represents 11.5% of the total flow in the Red Deer at Bindloss during the period and about 21% of the gross diversions into the Western and Eastern Irrigation Districts.

Further stations are now being established along this and other Alberta rivers where return flow is anticipated to try and determine the net depletion or acretion to the streams due to irrigation.


MAP OF
ALBERTA, SASKATCHEWAN
AND
MANITOBA
CONSUMPTIVE USE REQUIREMENTS
FOR
MAXIMUM CROP YIELD
USING
BLANEY CRIDDLE METHOD
COMPILED BY A.G. UNDERHILL — P. ENG.
1963
(IN INCHES)
ALBERTA
SASKATCHEWAN
MANITOBA
MINNESOTA
DAKOTA
SWIFT CURRENT
MOOSE JAW
REGINA
PORTAGE LA PRAIRIE
WINNIPEG
18
18.5
19
19.5
20
20.5
21

It is interesting to note that the return flow studies made by the Federal Water Resources Branch have already proved that the return flow estimates in general have been too low. Further research is necessary to determine a reasonable figure for each district. In the meantime an estimate as mentioned earlier is the only means of determining the percentage of the gross diversion returned for downstream use and since it is an estimate it would be much better to be on the low side than the other way.

Calculations.

Consumptive Use:

The Blaney-Criddle method was used in calculating the consumptive use.

It was necessary to decide on a cropping pattern in order to give the average requirement for a particular type of farm.

This farm was considered to have:

40% of the irrigable area in alfalfa
30% " " " " " grass
20% " " " " " grain
10% " " " " " special crops
100%

With this cropping pattern a determination of the crop coefficient "k" was possible for this particular unit. This unit was considered as being the average for the districts when they will be completely developed at some time in the future.

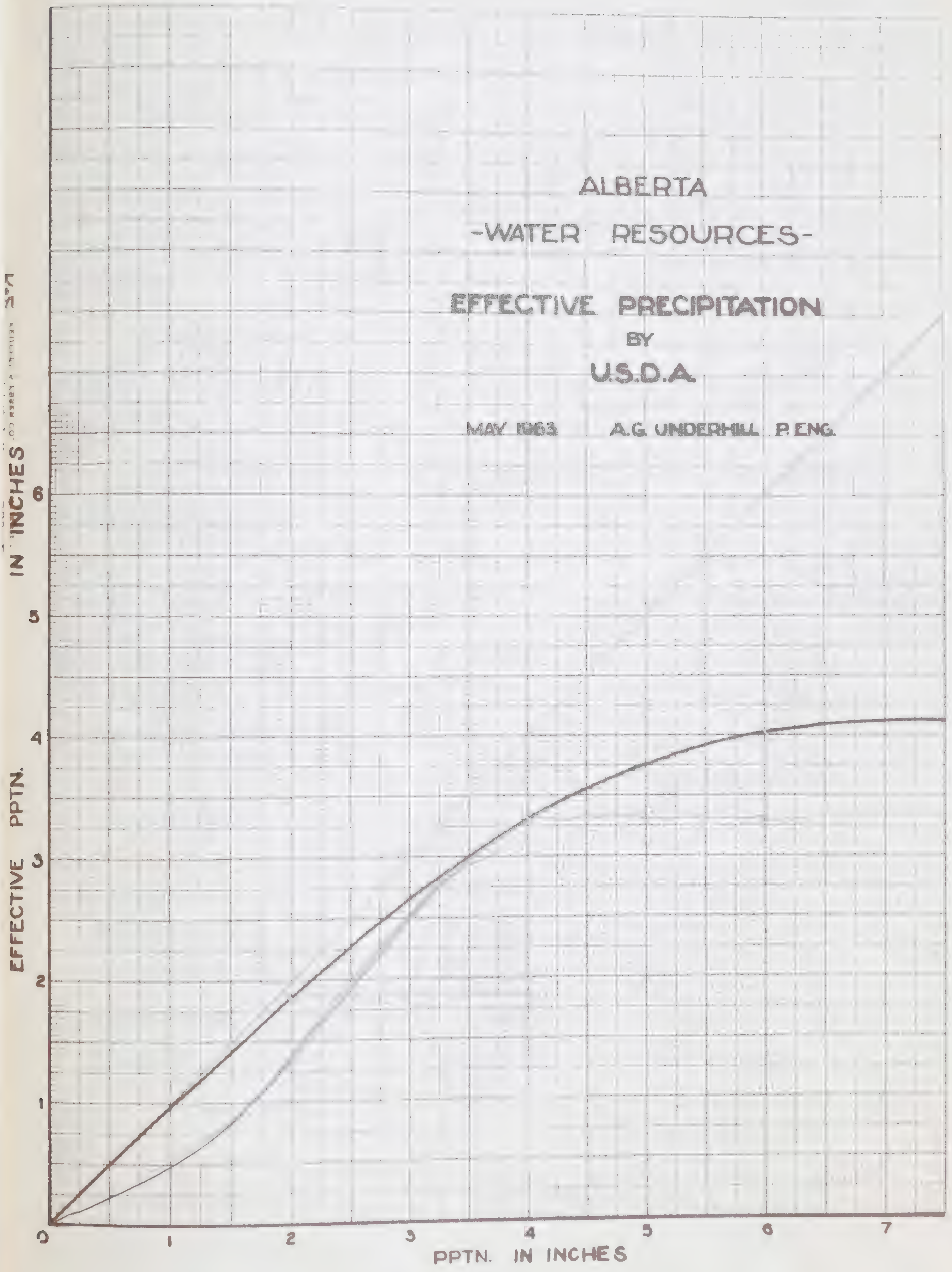
In these calculations no winter precipitation was considered since under good irrigation practice the soil reservoir would be filled by fall irrigation. In any case most of the winter precipitation occurs as runoff.

Consideration was given to crops not being sown in early May and those harvested in late August or September.

A summary of the results of these calculations is included in the appendix. These are the totals for the average year which were calculated on a monthly basis. Fig. 1 is a map showing the consumptive use for the prairie provinces as calculated by the Blaney-Criddle method.

Irrigation requirements were calculated by deducting from the plant consumptive use an estimate of the effective precipitation.

Only part of the precipitation measured reaches the root zone of the plants for evapotranspiration. If the showers are short and the weather hot nothing may reach the plant roots. Conversely if the rain is heavy some of the precipitation will pass right through the root zone and will not be available for plant use. Surface runoff may also occur. There are, therefore, many factors governing the amount of precipitation which will be effective in plant growth.



ALBERTA
-WATER RESOURCES-

EFFECTIVE PRECIPITATION
BY
U.S.D.A.

MAY 1963 A.G. UNDERHILL P.ENG.

Mr. A.D. Hopkins of the U.S.D.A. published an estimate of the amount of precipitation that can be assumed effective which has been accepted by the United States Department of Agriculture. Fig. 2 is a graph of this estimate which was used in the compilation of the effective precipitation in this study.

Farm efficiency, which we realized is probably much lower than the 60% we had decided to accept, will probably not be reached for some time in the future. However this will also be true of the irrigated areas. They will not reach their maximum use for some time. These two items have a balancing effect. When the irrigable area reaches its peak then the farm efficiency will be on the way to its peak and hence while we may be assuming that we are much more efficient now than we actually are we also have water which will be allocated for undeveloped acreage.

We are also of the opinion that as the demand for better irrigation practices and the pressure to be more efficient increases that the projects will reach an average efficiency of 60%. For this reason the 60% has been used.

Conveyance losses as mentioned have been related to the information given by various projects as have return flows.

The requirements based on these calculations for various projects which presently have either allocations or tentative allocations by the Prairie Provinces Water Board are included below.

Calculation of Alberta's Requirements.

E.I.D. Irrigable area	281,000 acres	
	x1.04	Irrigation required 12.5 in.
Plant irrigation requirements	292,240	Ac. Ft.
	x 1.67	60% Farm Irrigation Eff.
Farm Delivery	488,041	Ac. Ft.
Conveyance Losses	1.67	40%
Gross Requirements	815,028	Ac. Ft.
Return Flow	326,011	40% Return Flow
Net Diversion	489,017	Ac. Ft.

SMRD

Irrigable area	465,000 acres	
Plant requirements	.98 ft.	11.75 inches
Plant irrigation requirements	455,700	Ac. Ft.
	1.67	60% Farm irrigation eff.
Farm Delivery	761,019	Ac. Ft.
Conveyance loss	1.54	35%

Gross Requirements	1,171,969	Ac. Ft.
Return Flow	410,189	35%
Net Diversion	761,780	

Bow River Project

Irrigable area	240,000 acres	
	1.04	12.5
	249,600	Ac. Ft.
	1.67	60% Farm irrigation eff.
	416,832	Ac. Ft.
Conveyance losses	1.67	40%
Gross	696,109	Ac. Ft.
Return Flow	243,638	35% return flow
Net Diversion	452,471	

United Irrigation District

Irrigable area	34,000 acres	
	.79	9.5 inches
	26,860	Ac. Ft.
	1.67	60% Farm irrigation eff.
Farm Delivery	44,856	Ac. Ft.
Conveyance loss	1.42	30%
Gross	63,695	
Return Flow	25,478	40%
Net Diversion	38,217	

Lethbridge Northern Irrigation District

Irrigable area	96,000 acres	
	.875	10.5 inches
	84,000	Ac. Ft.
	1.67	60% Farm irrigation eff.
Farm Delivery	140,280	
Conveyance loss	1.30	23%
Gross	182,364	
Return Flow	63,827	35%
Net Diversion	118,537	

Aetna

Irrigable area	7,300 acres	
	.79	9.5 inches
	5,767	Ac. Ft.
	1.67	60% Farm irrigation eff.
Farm Delivery	9,631	Ac. Ft.
	1.54	35%
Gross	14,832	
Return Flow	5,932	40%
Net Diversion	8,900	

Leavitt

Irrigable area	4,400 acres	
	.79	9.5 inches
	3,476	
	1.67	60% Farm irrigation eff.
Farm Delivery	5,805	
	x1.54	35%
Gross	8,940	Ac. Ft.
Return Flow	3,576	40%
Net Diversion	5,364	

Mountain View

Irrigable area	3,600	
	.79	9.5 inches
	2,844	
	1.67	60% Farm irrigation eff.
Farm Delivery	4,749	Ac. Ft.
	x1.54	35%
Gross	7,313	Ac. Ft.
Return Flow	2,925	40%
Net Diversion	4,388	Ac. Ft.

Western Irrigation District

Irrigable area	7,500 acres	
	.83	10.0 inches
	62,250	
	x1.67	60% Farm irrigation eff.
Farm Delivery	103,958	
Conveyance loss	1.43	30%
Gross	148,659	
Return Flow	74,330	50%
Net Diversion	74,329	Ac. Ft.

5000	500 Stockwater deliverys @ 10 Ac. Ft./Ac.		Farm delivery
1.43		1.43	
7150	Gross	14.3	Ac. Ft.
5350	Return Flow	10.7	75%
1800 Ac. Ft.	Net	3.6	Ac. Ft.

Total W.I.D.

Farm Delivery 103958 + 5000 = 108,958 Ac. Ft.

Gross 148659 + 7150 = 155,809 Ac. Ft.

Return Flow 74330 + 5350 = 79,680 Ac. Ft.

Net Diversion 74329 + 1800 = 76,129 Ac. Ft.

Macleod	5,000 acres	
	.83	10 inches
	4,150	
	1.67	60%
	6,931	Ac. Ft.
	1.33	25%
Gross	9,218	Ac. Ft.
Return Flow	3,687	40%
Net Diversion	5,531	Ac. Ft.
Small Projects	70,000	
	x	12 inches
	70,000	
	1.67	60%
	116,900	
	1.42	30%
Gross	165,998	
Return Flow	49,799	30%
Net Diversion	116,199	

The Western Irrigation District represents a special case where we estimate the irrigation may again reach 75,000 acres in the future but where the district serves a considerable number of farms with water for stock only i.e. domestic supplies. When the demand for irrigation water is high the losses due to the supply of domestic water are small due to the fact the same canals and drains are used for both and the losses can be charged to supplying irrigation water. However in years when the irrigation requirements are small the losses charged to supplying stockwater are high. Except for evaporation a major portion of this flow is returned either as surface or subsurface flow to streams where it can be used downstream.

In order to satisfy this demand which now supplies an estimated 500 quarters with stockwater we recommend the following procedure be used i.e. that for every quarter just supplied with stockwater but no irrigation an allowance of 10 Ac. Ft. per year be allowed. This is to include all losses downstream from the point of delivery. This would for example on the Western Irrigation require 14.3 Ac. Ft. as a gross diversion. The return flow would be estimated as 75% of the gross diversion or 10.7. Thus the consumptive use would be 3.6 Ac. Ft./year per quarter. The evaporation on this water particularly in the W.I.D. is high so that the net used by the animals would be probably less than 1.5 Ac. Ft./year.

We admit this is just a suggestion and further investigation is necessary to assess the demands for stockwatering purposes since this may become an important facet of future development like the Wm. Pearce project. We would therefore, also recommend that further studies be made to determine the requirements to supply stock

water in natural and artificial channels.

We have asked the co-operation of the W.I.D. in doing further assessment on this problem.

We must also note, that, it may not be economical, or a most beneficial use, to allow water to run in these channels throughout the irrigation season and it may in the future when the values and need for conservation of the supply becomes great be necessary to restrict these diversions to once or twice during the season and to construct dugouts or other storage facilities to carry the cattle over the periods in between deliveries.

Calculation - Saskatchewan Requirements.

S. Sask. Project

Proposed irrigable area	470,000 acres	
	x1.04	Irrigation Req'd 12.5 inches
Plant irrigation requirements	488,800	Ac. Ft.
	x1.67	60% irrigation eff.
Farm Delivery	815,296	Ac. Ft.
Conveyance losses	1.67	40%
Gross requirements	1,363,214	Ac. Ft.
Return Flow	477,125	35%
Net Diversion	886,089	

Swift Current Project

Irrigable area	21,000 acres	
	.96	Irrigation req'd 11.5 inches
Plant irrigation requirements	20,160	Ac. Ft.
	1.67	60% irrigation eff.
Farm Delivery	33,667	Ac. Ft.
Conveyance losses	1.67	40%
Gross requirements	56,224	Ac. Ft.
Return Flow	22,490	40%
Net Diversion	33,734	Ac. Ft.

French Flats - Valley Park

Irrigable area	6,502 acres	
	1.0	Irrigation req'd 12 inches
	6,502 acres	
	1.67	60% irrigation eff.
	10,858	
	1.67	40%
	18,133	
	7,253	40%
	10,880	Ac. Ft.

SUMMARY

	Irr. Area	Present Allocation	Gross Div. Req.	Return Flow	Net Diver- sion	Gross Div. Ac.Ft./Ac.	Net Diver- sion	Net Irr. Req.	Conveyance Loss	Return Flow
Western	75,000	85,700	155,809	79,680	76,129	2.07	1.01	.83	30	50
Eastern	281,000	562,000	815,028	326,011	489,017	2.90	1.74	1.04	40	40
B.R.D.	240,000	478,534	696,109	243,630	452,471	2.90	1.89	1.04	40	35
S.M.R.D.	465,000	796,000	1,171,969	410,189	761,780	2.54	1.65	0.98	35	35
L.N.I.D.	96,000	150,000	182,364	63,827	118,537	1.90	1.24	.88	23	35
United	34,000	51,000	63,695	25,478	38,217	1.87	1.21	.79	30	40
Aetna	7,300	13,000	14,832	5,932	8,900	2.03	1.22	.79	35	40
Leavitt	4,400	7,000	8,940	3,576	5,364	2.03	1.22	.79	35	40
Mountain View	3,600	6,000	7,313	2,925	4,388	2.03	1.22	.79	25	45
Macleod	5,000	8,000	9,218	3,687	5,531	1.84	1.10	.83		
Small Projects	70,000	80,000	165,998	49,799	116,199	2.37	1.66	1.00		
	1,281,300	2,237,234	3,291,275	1,214,742	2,076,533					

The immediate question will be of how do these calculations check with former calculations and others made elsewhere.

First the consumptive use calculations supplied to me by the South Saskatchewan Rivers Development Commission for Outlook give a consumptive use requirement of 20.23 inches as compared to 20.62 inches by our calculations. The difference being the difference in the assumed crop pattern.

They do not use effective precipitation in their calculations and the farm efficiency is varied with various crops. However they come up with a farm delivery requirement of 21.84 inches as compared to our 22.04 inches indicating close agreement with their calculations.

The calculated requirements for consumptive use check well with those calculated the measured consumptive use at Swift Current.

Calculated	20.17 inches
Measured	
Wheat	21.1 inches
Pasture	21.5 "
Special Crops	20.2 "

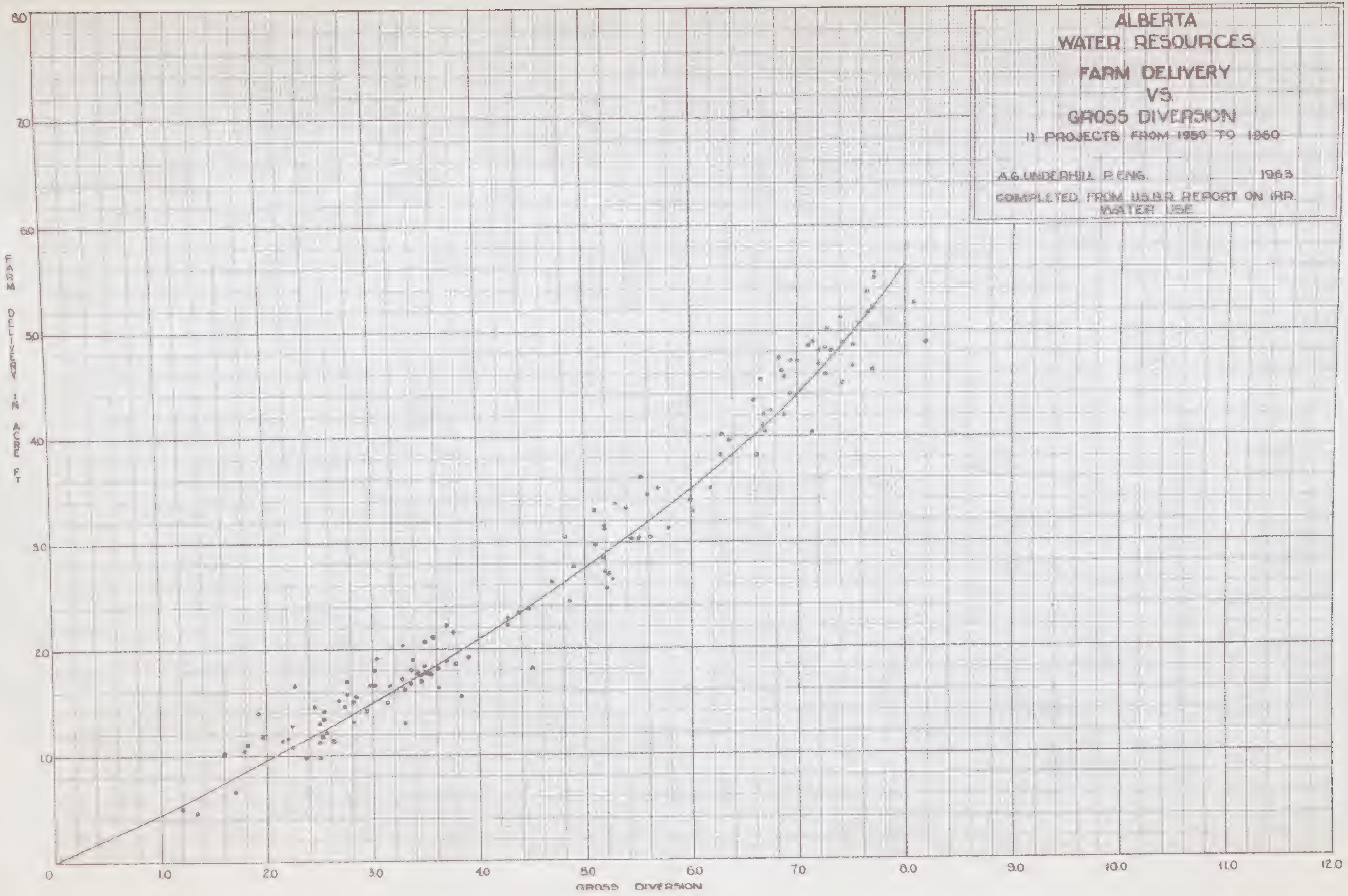
In Montana if we use their calculated figures which also compare to what measured information is available we find that for a similar crop pattern to that suggested here on the Milk River Project they would require 21.2 inches for crop consumptive use. Our Manyberries station, from our calculations would require 20.42 inches.

In our project calculations we find:

Project	Calculated Requirements	Average 1945-1961	Allocation
Western	2.07	9.2 (a)	1.71
Eastern	2.89	2.90	2.0
BRD	2.90	2.70	1.99
SMRD	2.54	2.40 (b)	1.71
LNID	1.90	1.90	1.56
UID	1.87	2.0	1.5
Aetna			1.78
Leavitt	2.03	2.1	1.59
Mountain View			1.67

(a) omitting 1951-54
(b) Est. based on 1960-63

We would note in some cases the projects are using less than this study suggests. This is due to the fact that in many cases the farmers only irrigate to the extent they must and not so that they can produce maximum crops. However as the


ALBERTA
WATER RESOURCES
FARM DELIVERY
VS.
GROSS DIVERSION
11 PROJECTS FROM 1950 TO 1960
A.G. UNDERHILL P.ENG.
1963
COMPLETED FROM U.S.B.R. REPORT ON IRR. WATER USE
FARM DELIVERY IN ACRE FT
GROSS DIVERSION
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0

population increases the water applied will be that which will produce maximum growth.

Figure 3 shows a graph of the farm deliveries for 11 Bureau of Reclamation projects from 1949 to 1960 plotted against the gross diversion requirements. You will note that present diversions for existing projects in Alberta have a similar trend i.e. for a farm delivery of 18 inches a diversion of 36 inches is required.

Houk in his book on Irrigation Engineering notes that the economic irrigation requirements in Montana average 1.68 Ac. Ft./Ac. as a farm delivery. The economic requirement is based on the amount of water which will produce a crop of maximum value taking into account the value of crop and water. He also notes that combined conveyance and irrigation efficiency are generally less than 33%. Overall efficiencies vary between 20 and 35% of gross diversions.

In 1915 Fortier noted that only one third of the water diverted serves a useful purpose in nourishing crops. In recent years Israelson has confirmed that this is substantially correct.

Golze cities records of the Bureau of Reclamation projects to show only 58.5% of the water diverted to the land actually reached the farm unit.

Blaney-Criddle estimate that 30% of the water diverted from a source actually becomes available for use by the plant in some areas. The other 70% is usually made up of transmission and distribution losses in unlined canals, laterals and farm ditches, application losses, evaporation, deep percolation and surface runoff account for the rest.

Blaney-Criddle produces the following table.

	General Soil Types		
	Open Porous	Medium Loam	Heavy Clay
Farm lateral loss	15%	10%	5%
Surface runoff loss	5%	10%	25%
Deep percolation loss	35%	15%	10%
Field irrigation efficiency	60%	75%	65%
Farm irrigation efficiency	45%	65%	60%

One of the major reasons for low irrigation efficiencies is the change of intake rate that occurs throughout the irrigation season and from year to year within the crop rotation period. Because of this rate of intake variation, which might change as much as 400% within any one season and at least double between seasons, considerable flexibility must be built into the irrigation system if high efficiencies are to be obtained. The size of stream per unit area must be larger when intake rates are high and smaller when intake rates decrease.

EFFECT OF METHODS OF IRRIGATION

The method of irrigation has considerable effect on the efficiency of application. Under some conditions, the highest application efficiency can be attained by the use of sprinklers.

Border irrigation, where adapted is conducive to relatively high efficiency in the use of water. At the other end of the scale wild flooding is probably the least efficient of all methods and is usually not justified when the cost of water is high. Flooding frequently results in non-uniform distribution and excessive waste of water and is likely to create serious drainage problems.

Efficient water application not only conserves the productivity of the soil but also helps keep the water under control. These are major goals in irrigation agriculture.

In the latest Bureau of Reclamation report on "Use of Irrigation Water" 1949 to 1960 actual measurements are present for 21 different irrigation projects to show all phases of their water use. The area most nearly comparable to our prairie provinces is Region 6 which included Montana, Wyoming and South Dakota irrigation projects. Information given for projects in this area.

Figure 4 shows the actual water use by the U.S. projects as well as an estimate of the breakdown of the farm delivery and return flow figures.

Here again actual measurements as well as estimates from experts in the field show that in areas adjacent to ours the proposed allocations and Alberta's present diversions are not excessive when compared to other areas.

We might note here that in the Royal Commission report on the South Saskatchewan Rivers Development they recognized that 1.5 Ac. Ft./Ac. was insufficient as a gross diversion rate.

Page 12, Article 14, reads as follows:

"For administrative purposes, the legal "duty of water" is fixed in Alberta at 1.5 feet. Thus is expressed as 1.5 acre feet for the irrigation season May 1st to September 30th. The duty of water is the quantity of water required to produce optimum growth of crops. It will vary from season to season. A duty of 1.5 acre feet for the crops on the South Saskatchewan project would be a safe estimate. To this must be added another 1.5 feet for transmission and other losses making a general duty of 3 acre feet. The project would require, therefore, about 1,350,000 acre feet annually when the irrigated area reaches 450,000 acres. The reservoir with a dam at the Third Meridian could contain upward of 8,000,000 acre feet of which 2,650,000 acre feet of water would be available for irrigation between full supplies levels of the reservoir and canals. Insofar as the present plans for irrigation upstream are concerned, there would be ample water left for the South Saskatchewan development".

					Distribution System Losses		Farm Delivery						
	Area Irrigable Acres	Canals & Laterals Miles	Miles Line	Gross Div.	Total Losses & Waste Ac.Ft./Ac.	Percentage of Total Div.	Total Ac.Ft./Ac.	Percentage of total	Cons.Use Ac.Ft./Ac.	Ppt. Effective Ft.	Farm Waste & Deep Percolation Ac.Ft./Ac.	Percentage	Return flow
Project													
Buffalo Rapids	22500	154.3	2.9	3.36	1.55	46.1	1.81	53.9	2.10	.78	.50	27.6	51.2
Missouri	9500	59.5	9.7	4.48	2.08	45.3	2.39	54.7	2.22	.70	1.30	52.7	55.6
Angostura Unit	-----												
Shoshone	21500	154.4	4	6.22	3.18	51.1	3.04	48.9	1.98	.57	1.65	54.3	72.5
Heart Mtn. Div.	-----												
Sun River	61900	551	6	3.15	1.64	52.1	1.51	47.9	1.92	.79	0.38	25.2	55.9
Greenfield Div.	-----												
		Based on Field Data							Estimated				

Figure 4.

In the paper "Land and Water and Future Requirements for Water" written by the Department of Agriculture for the U.S. Senate Select Committee on National Water Resources a study is made of irrigation water requirements for the present and the future.

In the Upper Missouri Basin, which most nearly compares to the area we are considering, they make the following estimates:

Annual Irrigation Water Requirements Upper Missouri Region	Year 1954	1980	2000
Net Irrigation Water required by plant	13 inches	13	13
Efficiency of farm application	45%	55	60
Total water required at farm headgate	29 inches	24	22
Storage and delivery efficiency	40%	45	50
Gross diversion requirements	73 inches	53	44
Return Flow	55%	55	55
Total irrigation requirement	40 inches	31	27

These figures were obtained by the Department of Agriculture using the best information available from all sources in the United States and probably represent the best available estimate of water requirements in that area.

These figures are presented to show that the estimates made by methods suggested in this report are not out of line and if anything are lower than similar ones made just to the south of this area.

Davis in his handbook lists the limits for large projects in the Western States as follows:

Diversions	2 to 10 Ac. Ft.
Canal losses	15 to 40% of diversions
Canal waste	5 to 30% of diversions
Deliveries to farm	30 to 70% of diversions
Deliveries to farms	1 to 7 Ac. Ft.
Surface waste	5 to 10% of deliveries
Percolation loss	5 to 60% of deliveries
Return Flow	20 to 60% of diversions
Consumptive use	1 to 3.5 Ac. Ft./Ac.

In the Duchesne project studies recently completed by the State Engineer in Utah an overall efficiency of 40% was assumed for the area.

In its Handbook the Bureau of Reclamation notes:

"In practise it is infeasible to supply crop irrigation requirements without losses and waste. Losses are deep percolation and waste. Usually deep percolation losses run 15% to 50% of water applied. Sprinkler irrigation under exceptional conditions 5%, wild flooding and continuous flooding 70%. Surface farm wastes are ordinarily about 5% but may range from 0 to 20% or more depending on care of application.

Evaporation is ordinarily negligible, e.g. 100 miles of canal, 40 feet wide has a surface area of 485 acres and the maximum monthly evaporation would total only 200 to 250 acre feet, only a fraction of the total monthly loss or waste.

Vegetation along or in canals takes a small toll of water from canals but in many cases water is drawn from seepage. Bank and channel storage may be factors to be considered in some situations".

Seepage loss and waste.

Waste - may be negligible to 50%, depending on excellence of system average less than 5%.

Israelson in his book on Irrigation Principles and Practises notes that thirty nine efficiency of application tests on one group of farms in Utah resulted in an average of 38% application efficiency, 30 of the tests or 77% gave an average of less than 50%. The dominant factors contributing to low efficiencies in these 30 irrigations were:

(a) excessive applications	14
(b) uneven distribution of water	7
(c) excessive moisture content prior to irrigation	5
Combination of (a), (b) & (c)	4
	30

Ninety on second group of farms averaged 44%.

In 17 western states in 1940, 125,000 miles of irrigation canals 90,000,000 Ac. Ft. diverted 38% lost between diversion and delivery.

Delivery efficiency therefore = 62%.

In the U.S. Dept. of Agriculture Water Handbook I. J. Bamesbury points out the following:

On many farms 3/4 of the irrigation water is wasted. Considering the importance of water, it is worth emphasizing again the about 1/3 of all water diverted for irrigation is lost conveying it to the land and that another 1/3 percolates too deeply or runs off during the process of application to the land. Some loss is a legitimate accessory to use, but losses of this order cannot long be tolerated.

The major part of loss on conveyance can be attributed to seepage, which can largely be eliminated by lining the irrigation canals. Other conveyance losses, such as operational wastes can be reduced by better management. In 1950 Census of Agriculture lists 19% lost in conveyance. According to the Bureau of Reclamation 37% of all the water diverted on 46 of its projects in 1946 was lost in conveyance, 23% was attributed to seepage and 14% to operational waste. 30% of water used by sprinkler lost to evaporation from spray, evaporation from leaves, unequal distribution of water and deep percolation.

All these reports are included as a justification of the assumptions made in calculating the water requirements for existing projects. After due consideration of these reports and information we recommend that the following method be accepted as a basis for calculation of the irrigation requirements for a project.

1. That the consumptive use requirement for a project be calculated by the Blaney-Criddle method when figures are not available for actual consumptive use.

2. That a farm efficiency of 60% be used in calculating the farm delivery requirement unless better information is available.

3. That conveyance losses be estimated on the basis of general knowledge of conditions and comparison with other areas until and unless better information is available.

4. That return flow be estimated on the basis of general information and knowledge until and unless more accurate information is available.

You will note that there is much room for improvement in the estimates of farm efficiency and return flow as well as consumptive use and conveyance losses and we would recommend that every effort be made to have studies made to improve the methods used in these calculations.

We believe as time progresses and more meteorological data is available that more sophisticated methods of calculation may be used but when one considers the wide range of variables involved these calculations may not be justified.

It would appear that one avenue of research should be into the use of evaporation data for consumptive use calculations. Evapotranspiration most nearly compares to evaporation and should possibly be the least expensive method.

Figure 5 is a suggested form for the calculation of irrigation water use.

Figure 5

PROJECT: ____

IRRIGABLE AREA: ____________ acres.

IRRIGATION FACTOR: ____________ acres.

NET AREA IRRIGATED: ____________ acres.

CALCULATION OF WATER REQUIREMENTS

1. Plant Consumptive Use (a) by measurement ____________ inches

   (b) by formula ____________ inches

2. Rainfall During Growing Season _____ inches
   Effective Rainfall (approved graph) ____________ inches

3. Net Irrigation Requirements a) (1)-(2) ____________ inches

   b) $\frac{(1)-(2)}{12}$ x (Acres) ____________ Ac.Ft.

4. Irrigation Efficiency (a) by measurement ____________

   (b) _____ % (Est.) ____________

FARM DELIVER $\frac{(3)}{\text{Irr. Eff.}}$ ____________ inches ____________ Ft.

TOTAL FARM DELIVER (Net Area Irr.)x(Farm Delivery) _________ Ac. Ft.

5. Conveyance Losses (a) by measurement ______ % of Gross Diversion ______ Ac. Ft.

   (b) by estimation ______ % of Gross Diversion ______ Ac. Ft.

6. Reservoir Losses (a) by measurement ______ Ac. Ft.

   (b) by estimation ______ Ac. Ft. = ______ % of Gross Diversion

7. Gross Irrigation Requirements _________ Ac. Ft.

8. Return Flow (a) measured ______ Ac. Ft. ______ % of Gross Diversion

   (b) estimated ______ Ac. Ft. ______ % of Gross Diversion

9. Net Depletion (7-8) _________ Ac. Ft.

APPENDIX.

(1) Definition of terms

(2) Typical calculations

(3) Reference

DEFINITION OF TERMS

Canal Losses

The quantity of water lost due to leakage, seepage and evaporation in the canal system. In irrigation projects these are the losses in the canal system between the point of diversion and point of delivery to the farm unit.

Consumptive Use

The amount of water used by plants in transpiration and growth, plus the water vapor lost from the adjacent soil, snow, or intercepted precipitation in any specified period of time on any given area.

Conveyance Losses

The water lost due to leakage, seepage, or evaporation in transporting water in canals, reservoirs or other systems from the point of diversion from a stream, lake, reservoir or other source of supply to the point of use.

In irrigation projects these are the losses between the point of diversion and the point of delivery to the farm unit.

Deep Percolation

Is the movement of water under hydrostatic pressure through the soil profile after it reaches a point below the root zone of the crop or vegetation.

Drought

A period of dryness of sufficient length to deplete soil moisture to the extent that plant growth is seriously retarded.

Duty of Water

The quantity of water to be supplied by artificial means to insure maximum crop production measured at the farm headgate.

Effective Precipitation

That portion of the precipitation falling on an area during the growing season which is effective in meeting the consumptive use requirements of vegetation.

Evaporation

The process by which water is changed from a liquid or solid state into a vapor state.

Evapotranspiration

The water lost from the soil by evaporation and by plant transpiration.

Gross Diversion Rate

Is the maximum rate of diversion from a source of supply required to satisfy the demands of a project.

Gross Diversion

Is the total amount of water diverted from a source of supply in any one year to satisfy all the demands of an irrigation project.

Groundwater

The water which is held in all the unblocked pores of the material underlying the water table. The water table is the upper limit of the saturated material.

Infiltration Capacity

Is the total amount of water which can be held in the soil profile without causing surface runoff.

Infiltration Rate

Is the maximum rate at which water can enter the soil profile.

Interception Loss

That portion of the precipitation that is intercepted by the plant growth and does not reach the soil surface.

Irrigable Area

The area of a piece of land which can be artifically supplied with water to increase crop production. Farm buildings, roads, minor distribution canals, etc. are generally included in the irrigable area.

Irrigation

The controlled application of water to arable lands to supply the water requirements of plants, to give maximum plant growth, not supplied by precipitation or groundwater.

Irrigation Efficiency

The percentage of irrigation water diverted that is stored in the soil and available for consumptive use by the crops.

Farm Irrigation Efficiency

The percentage of irrigation water that is stored in the soil and available for consumptive use as measured at the farm headgate.

Farm Irrigation Efficiency

The percentage of irrigation water that is stored in the soil and available for consumptive use or measured at the field level.

Irrigation Factor

The percentage of the total irrigable area of a project actually irrigated in any one year.

Irrigation Requirements

Is the quantity of water exclusive of precipitation that is required to give maximum crop growth. It includes evapotranspiration, surface evaporation, deep percolation and any other economically unavoidable wastes of water. It does not include any losses which occur during delivery of the water to the farm headgate.

Lysimeter

A structure containing a mass of soil which permits the measurement the effect of plant cover on the movement of water over, in and through the soil profile.

Net Diversion

The difference between the gross diversion to a project from the source of supply and the amount of water returned from that project to a source of supply.

Percolation

The downward movement of water through the soil profile under hydrostatic pressure.

Potential Evapotranspiration

The water consumed by plants and lost by evaporation providing that at no time there is a deficiency in the water supply available for maximum growth by the plants or vegetation.

Precipitation

Is the amount of moisture falling on an area during a period in the form of rain, snow, dew, etc.

Project Irrigation Efficiency

The percentage of irrigation water as measured at point of diversion that is stored in the soil and available for consumptive use as measured at the point of diversion.

Reservoir Losses

The quantity of water lost due to leakage, seepage and evaporation from the various reservoirs in a project.

Return Flow

Is that portion of the water diverted for use on a project which is returned to a source of supply in the form of surface or underground flow.

Riparian Rights

The common law right of any person owning land which borders on a stream to use water from that stream for domestic purposes.

Transpiration

The net quantity of water absorbed through the crop roots and transpired, plus that used directly in building plant tissue. It does not include evaporation from the soil or intercepted precipitation.

Seepage

The escape of water through the soil, or water emerging from an area of soil along an extensive line of surface, in contrast to springs where water emerges from a local spot.

Streamflow or Total Runoff

That portion of the precipitation which reaches the ground surface and moves laterally to a drainage course. It includes surface and subsurface runoff.

Subsurface Runoff

That portion of the precipitation which on reaching the soil surface enters the soil profile and moves laterally to some drainage course through the soil profile.

Surface Runoff

That portion of the precipitation which on reaching the ground surface proceeds directly over the surface to reach a drainage course.

Supplemental Irrigation

The water supplied for irrigation is of a supplementary nature and is second to precipitation as a source of supply for the vegetation concerned.

TYPICAL CALCULATIONS

The calculations in this report were done by the Blaney-Criddle method. A typical set of calculations for Vauxhall, Alberta follows:

DATA AVAILABLE

Month	Temp.	Pptn.	p	k	u	r	Irr. Req'd
May	51.8°F	1.62	10.69	.25	1.38	1.48	.10
June	58.5	2.08	10.93	.76	4.80	1.85	2.95
July	65.8	1.62	10.99	.95	6.83	1.50	5.33
Aug.	62.8	1.33	10.00	.85	5.35	1.25	4.10
Sept.	53.1	1.32	8.44	.28	1.35	1.24	.11
Ave.	58.4 °F	7.97			19.71	7.32	12.39 inche

Temp. from Meteorological report 1920-1951.

Precipitation from Meteorological report 1920-1951.

p from table for daylight hours at 50°N Lat.

k was calculated on the basis that an average farm acreage would be composed of:

Alfalfa	40%
Grass	30%
Grain	20%
Specialized Crops	10%
	10%

and using a Blaney-Criddle K for Vauxhall

of Alfalfa = .78

Grass = .73

Grain = .87

Specialized Crops = .59

The monthly k's were computed as follows:

	k
May	.25
June	.76
July	.95
Aug.	.85
Sept.	.62
K =	.62

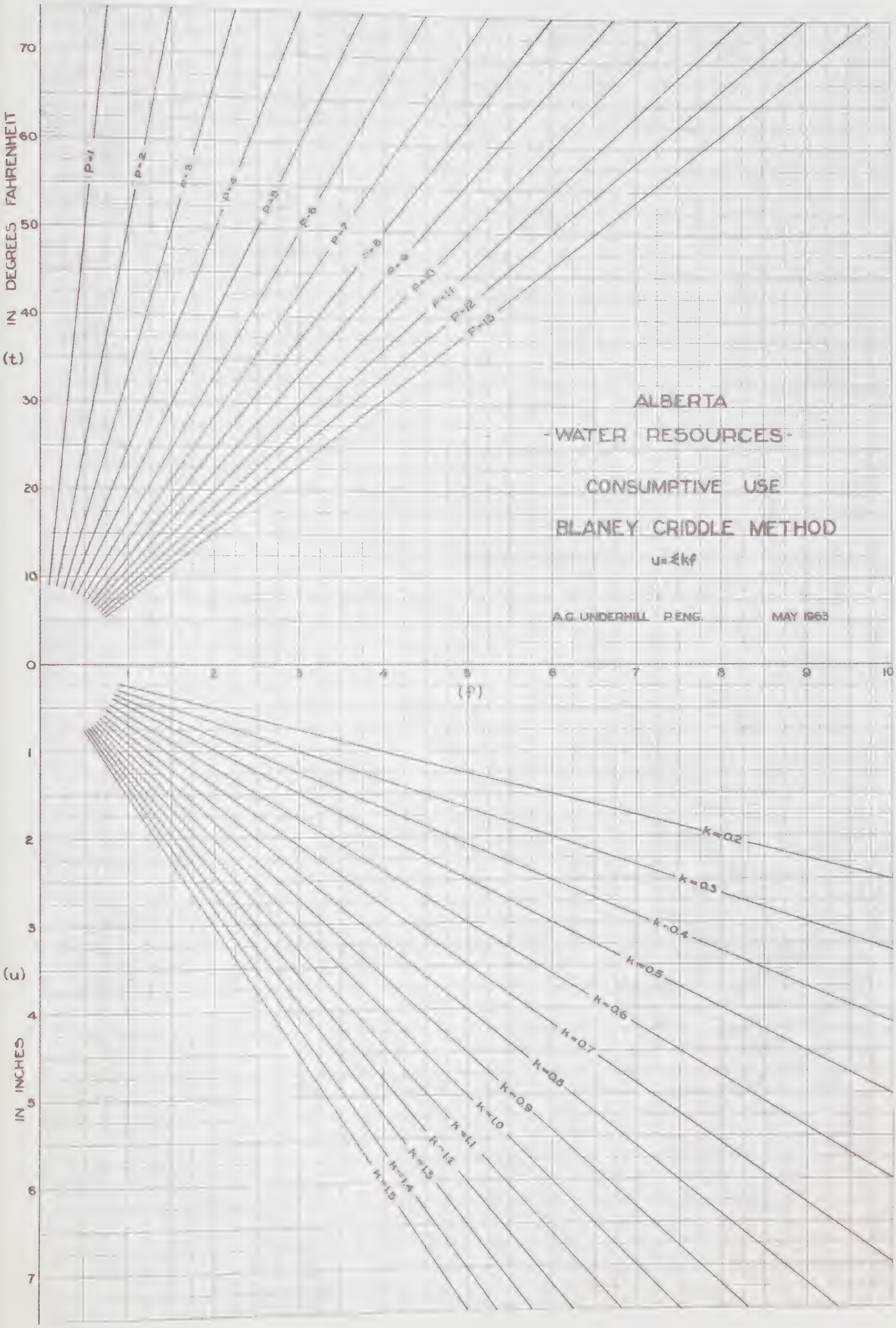
These figures included corrections for crops not using moisture in May, August and September.

u was calculated using a graph of $U = \sum kf$

r is effective rainfall and calculated using a graph to reduce the normal rainfall to take care of losses and excessive precipitation.

The irrigation requirement was calculated by deducting the effective rainfall from the crop consumptive use (a).

Maps were prepared showing consumptive use contours and irrigation requirements for the average conditions.



ALBERTA
-WATER RESOURCES-

CONSUMPTIVE USE
BLANEY CRIDDLE METHOD

$u = \Sigma kf$

A.G. UNDERHILL P.ENG. MAY 1963

The attached tables show the results of using the Blaney-Criddle method for various stations in the Prairie Provinces using the Blaney-Criddle method calculation of consumptive use.

CONSUMPTIVE USE CALCULATION ALBERTA

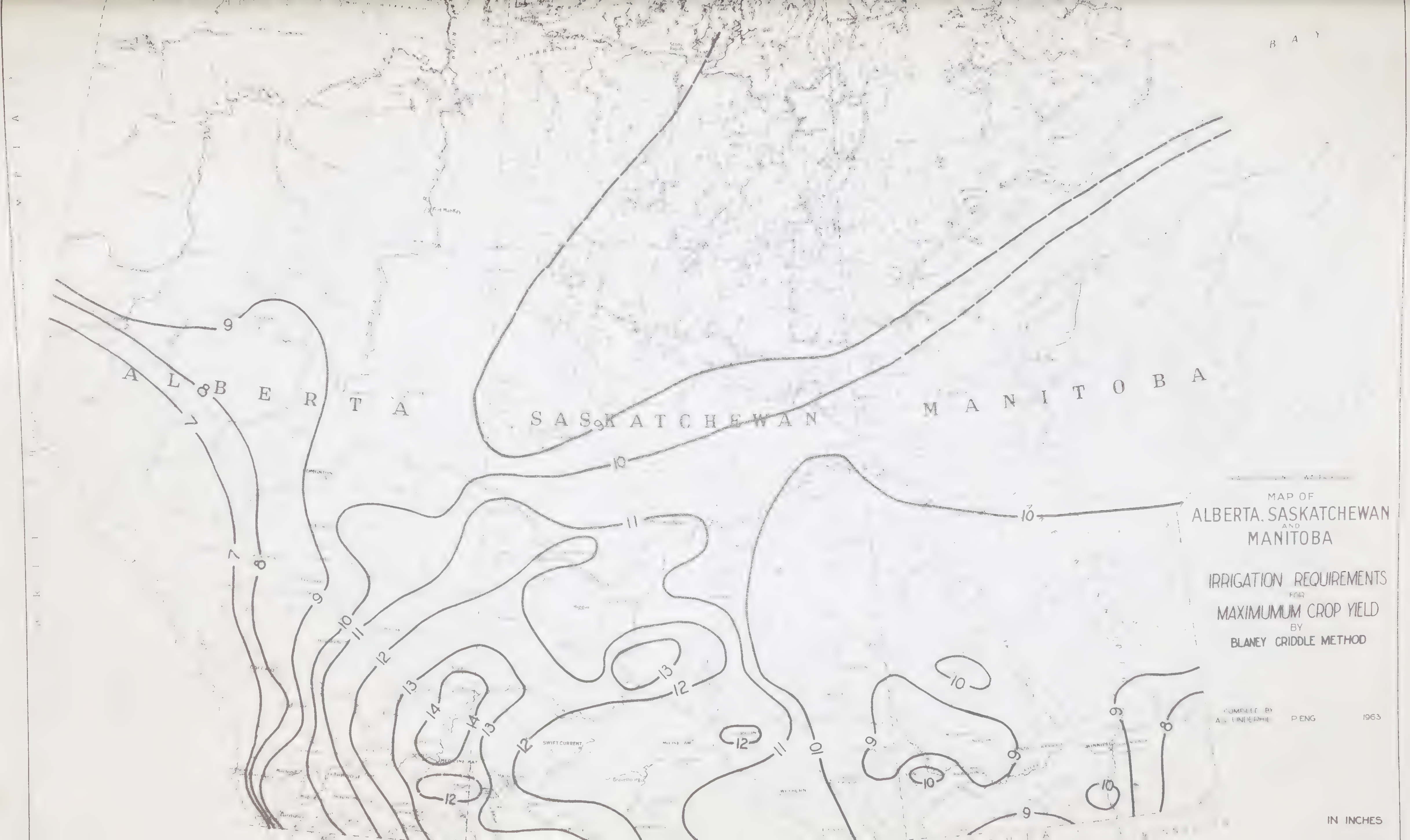
Station	Consumptive Use inches	Effective Rainfall inches	Irrigation Requirements inches	$\frac{r}{u}$
Vauxhall	19.71	7.32	12.39	37.2
Lethbridge	19.25	8.94	10.31	46.4
Medicine Hat	21.59	7.54	14.05	34.9
Cowley	19.20	9.85	9.35	51.3
Calgary	18.99	10.42	8.51	54.9
Cardston	19.20	9.73	9.47	50.7
Coronation	19.32	8.15	11.17	42.2
Carway	18.92	9.15	9.72	48.4
High River	18.34	10.57	7.77	57.6
Gleichen	19.65	8.27	11.38	42.1
Strathmore	19.19	9.13	10.06	47.6
Drumheller	20.10	5.63	14.47	28.0
Brooks	20.24	7.62	12.62	37.6
Hanna	19.52	7.80	11.72	40.0
Foremost	20.35	8.11	12.24	39.9
Manyberries	20.42	6.24	14.18	30.6
Empress	20.71	6.01	14.70	29.0
Hughenden	19.44	8.87	10.57	45.6
Stettler	19.13	9.92	9.21	51.9
Olds	18.97	10.76	8.21	56.7
Vermilion	19.59	10.18	9.40	52.0
Lloydminster	19.91	8.24	11.67	41.4
Naco	19.59	7.24	12.35	37.0
Red Deer	18.64	10.44	8.20	56.0
Kananaski	17.64	12.57	5.07	71.3
Jenner	20.17	6.70	13.44	33.2
Three Hills	19.11	9.31	9.80	48.7
Camrose	19.36	9.05	10.31	46.7
Edmonton	19.77	9.58	10.9	48.5
Elk Point	19.58	10.17	9.41	51.9
Lac La Biche	19.89	9.98	9.91	50.1
Athabasca	19.05	9.74	9.31	51.1
Edson	18.56	11.71	6.85	63.0
Fort McMurray	19.44	10.01	9.43	51.4
Dunvegan	19.55	7.19	12.36	36.8
Fort Chipewyan	19.86	7.48	12.38	37.7
Wabaska	19.82	10.79	9.03	54.4
Fort Vermilion	19.89	7.49	12.40	37.7
Jasper	18.52	6.78	11.74	36.6
Hay River, N.W.T.	19.24	6.35	12.89	33.0

CONSUMPTIVE USE CALCULATIONS SASKATCHEWAN

Station	Consumptive Use inches	Effective Rainfall inches	Irrigation Requirements inches	$\frac{r}{u}$
Chaplin	20.18	8.06	12.12	39.9
Scott	19.38	8.15	11.25	42.1
Prince Albert	20.07	8.97	11.07	44.7
Spiritwood	19.14	8.67	10.47	45.3
Melfort	19.65	9.55	10.10	48.6
Nokomis	19.87	7.57	12.10	38.1
Foam Lake	19.87	10.46	9.21	52.6
Lentlaw	19.14	9.83	9.31	51.4
Moosomin	19.85	11.37	8.48	57.3
Gravelburg	20.25	9.22	11.03	45.5
Saskatoon	20.15	8.77	11.38	43.5
Hudson Bay	19.33	9.77	9.56	50.5
Kamsack	19.77	9.58	10.19	48.5
Lac La Ronge	19.36	10.25	9.09	52.9
Loon Lake	19.02	10.02	9.00	52.7
Fond Du Lac	19.02	6.75	9.27	35.5
Willow Creek	20.61	7.14	13.47	34.6
Consul	19.35	7.14	12.25	36.9
Maple Creek	20.14	7.96	12.18	39.5
Leader	20.62	7.28	13.34	35.3
Alsask	20.02	6.84	13.18	34.2
Macklin	19.79	8.05	11.74	40.7
North Battleford	20.38	8.11	12.27	39.8
Rosetown	19.95	8.36	11.59	41.9
Kindersley	19.99	7.39	12.60	36.9
Swift Current	20.17	9.03	11.14	44.8
Val Marie	19.72	6.73	12.99	34.1
Assiniboia	20.07	8.95	11.12	44.6
Moose Jaw	20.46	8.76	11.70	42.8
Regina	19.99	7.39	12.60	37.0
Strasbourg	19.68	8.72	10.96	44.3
Pilger	19.59	8.92	10.67	45.5
Leross	18.69	9.29	9.40	49.7
Indian Head	20.74	9.38	11.36	45.2
Yellow Grass	19.98	9.48	10.50	47.4
Estevan	20.31	9.78	10.53	48.2
Carlyle	19.57	9.80	9.57	50.1
Beechy	20.24	7.99	12.25	39.5
Yorkton	19.92	9.86	9.86	49.3
Elbow	20.29	7.22	13.07	35.6
Broadview	19.31	10.02	9.29	51.9
Outlook	20.62	7.42	13.20	36.0
Dundurn	20.03	8.03	12.00	40.1
Davidson	20.06	7.84	12.22	39.1
Tugaske	20.10	8.16	11.94	40.6
Biggar	20.22	8.47	11.75	41.9

CONSUMPTIVE USE CALCULATION MANITOBA

Station	Consumptive Use inches	Effective Rainfall inches	Irrigation Requirements inches	$\frac{r}{u}$
Russell	19.57	10.79	8.78	55.1
Virden	20.50	10.36	10.14	50.5
Pierson	20.14	10.27	9.87	51.0
Boissevain	19.79	10.72	9.07	54.2
Brandon	20.08	11.36	8.72	56.6
Neepawa	20.22	11.36	8.86	56.2
Portage La Prairie	20.73	11.24	9.49	54.2
Cypress River	20.17	10.86	9.31	53.8
Morden	20.66	11.13	9.53	53.9
Morris	20.93	10.70	10.23	51.1
Emerson	20.84	11.24	9.60	53.9
Sprague	19.57	12.29	7.28	62.8
Winnipeg	20.48	11.18	9.30	54.6
Souris	20.32	10.53	9.79	51.8
Graysville	20.48	10.65	9.83	52.0
Grenfill	20.24	10.27	9.77	50.7
Dauphin	20.57	10.28	10.24	50.0
Hamiota	20.13	11.16	8.97	55.4
Gimli	20.14	11.12	9.02	55.2
Pilot Mound	20.05	11.08	8.97	55.3
Ninette	20.16	11.01	9.15	54.6
The Pas	19.88	9.59	10.29	48.2
Cumberland House	19.42	9.58	9.84	49.3
Berens River	19.55	10.26	9.29	52.4
Bissett	20.36	11.23	9.13	55.2
Flin Flon	20.20	10.03	10.17	49.7
Island Falls	19.20	10.66	8.54	55.5
Norway House	19.51	8.77	10.74	45.0
Port Nelson	19.84	7.76	12.13	39.0
Churchill	17.14	8.97	8.17	52.3



MAP OF
ALBERTA, SASKATCHEWAN
AND
MANITOBA

IRRIGATION REQUIREMENTS
FOR
MAXIMUMUM CROP YIELD
BY
BLANEY CRIDDLE METHOD

COMPILED BY
A. S. UNDERHILL P. ENG 1963

IN INCHES

Use of Map Showing Irrigation Requirements

An example of the use of a map Fig. 7 showing the irrigation water requirements in the prairie areas is best taken from one of the existing projects.

The Eastern Irrigation District falls almost completely in between the lines showing an irrigation water requirement of 12 and 13 inches. We might average their requirements, therefore to be 12.5 inches per irrigable acre for maximum crop requirements. To this figure we must add the farm irrigation efficiency to obtain the farm delivery requirements. As mentioned elsewhere in this report a farm irrigation efficiency of 60% is considered to be attainable, although at the present time it is doubtful if any district in the Prairie Provinces approaches this figure. Using a 60% farm irrigation efficiency we get a farm delivery requirement of 20.9 ac. in./acre. In addition to this farm irrigation efficiency we must then add in our conveyance losses. In the E.I.D. the conveyance losses are estimate to be 40% of the gross diversion. So that we would require a gross diversion of approximately 35 inches to satisfy the demand of the E.I.D. Of this 35 inches only 12.5 inches or approximately 1/3 would be actually required by the plants. The remainder would be evaporation, seepage, waste. The latter two items make up the return flow, which as surface and subsurface flow make up an estimate 50% of the gross diversion or 18 inches.

Therefore for the E.I.D. we get:

Consumptive Use	12.5	inches	
Farm Losses	8.4	"	(farm efficiency 60%)
Farm Delivery	20.9	"	
Conveyance Losses	14.0	"	(40% losses)
Gross Requirements	34.9	"	
Return Flow	13.9	"	(40% return flow)
Net Depletion	21.0	"	

REFERENCES

1. Use of Irrigation Water U.S.B.R. 1949-1960

2. U.S. Senate Select Committee report on Water Resources 1960

3. Estimates of Irrigation Water Requirements for Crops in North Dakota by S. Davis, N. Evans, and A. Hazar

4. Estimated Water Requirements for crops in Irrigated Areas of Montana by O. Monson, W. Criddle and S. Davis

5. Methods for Estimating Consumptive Use of Water for Agriculture W. C. Munson. ASCE trans.

6. Determining Consumptive Use and Irrigation Water Requirements H. F. Blaney and W. D. Criddle. USDA Tech. Bulletin 1275

7. Irrigation Practise & Water Requirements for Crops in Alberta Snelson

8. Irrigation & Climate by Henry Oliver

9. Return Flow from Irrigation Districts 1957-62 Canada Dept. of N.A. & N.R.

10. Irrigation Annual reports for various Districts

11. An Engineer looks at Irrigation in Western Canada W. L. Foss

12. Estimating Irrigation Requirements from Meteorological Data G. W. Robertson and R. M. Holmes

13. Consumptive Use of Water for Agriculture R. L. Lowry, Jr. and A. F. Johnson 1940

14. Predicting Return Flow from Irrigation by P. A. Hurley U.S.D.A. #660

15. Water Requirements of Crops ASAE Publication SP-SW0162

16. A Summary of Water Resources Activities by the Western States 1961

17. Consumptive Use of Water by Major Crops in Texas Bulletin 6019 1960

18. Methods for Evaluating Irrigation Systems USDA Ag. Handbook #82

19. Design Manual Dept. of the Navy

20. Design Manual USBR

21. Measuring Seepage from Irrigation Channels USDA Tech. Bull. 1203

22. An Approach toward a Rational Classification of Climate C. W. Thornewaite

23. Efficiency of Water Use in an Irrigation District in Southern Alberta E. H. Hobbs and K. K. Krogman

24. Irrigation Engineering by Houk

25. Handbook of Applied Hydrology Davis

26. Irrigation Efficiency as it Influences Water Requirements for Crops by Glen H. Cannell ASAE

27. Duchesne Area Study Committee report Central Utah Project

28. Irrigation Principles and Practise by Israelson

29. Preparing Land for Efficient Irrigation by J. G. Bamesburg USDA Handbook Water

30. The Engineer and World Wide Conservation of Soil & Water
O. W. Israelson ASCE Publication

31. Methods of Computing Consumptive Use by Wayne D. Criddle 1958
ASCE Publication

32. The Overall Use of Water on the Bow River Irrigation Project
W. F. Hall

1806 /

HD
1698 Alberta. Dept. of Water Resources.
A32 Report on irrigation water
c.3. use study.

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